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HIGHWAY CONSTRUCTION

PART I

AMERICAN SCHOOL OF CORRESPONDENCE
AT
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO ILLINOIS
U.S.A.

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INSTRUCTION PAPER

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AMERICAN SCHOOL OF CORRESPONDENCE

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PART I.

COUNTRY ROADS.

GENERAL CONSIDERATIONS.

Object of Roads. The object of a road is to provide a way for the transportation of persons and goods from one place to another with the least expenditure of power and expense. The facility with which this traffic or transportation may be conducted over any given road depends upon the resistance offered to the movement of vehicles. This resistance is composed of: (1) The resistance offered by the roadway, which consists of (*a*) "friction" between the surface of the road and the wheel tires; (*b*) resistance offered to the rolling of the wheels, occasioned by the want of uniformity in the road surface, or lack of strength to resist the penetrating efforts of loaded wheels, thus requiring the load to be lifted over projecting points and out of hollows and ruts, thereby diminishing the effective load the horse may draw to such as it can lift. This resistance is called "resistance to rolling" or "penetration;" (*c*) resistance due to gravity called "grade resistance;" (2) The resistance offered by vehicles, termed "axle friction;" (3) Resistance of the air.

The road which offers the least resistance to traffic should combine a surface on which the friction of the wheels is reduced to the least possible amount, while offering a good foothold for horses, to enable them to exert their utmost tractive power, and should be so located as to give the most direct route with the least gradients.

Friction. The resistance of friction arises from the rubbing of the wheel tires against the surface of the road. This resistance to traction is variable, and can be determined only by experiment. From many experiments the following deductions are drawn:

(1) The resistance to traction is directly proportional to the pressure.

(2) On solid, unyielding surfaces it is independent of the width of the tire, but on compressible surfaces the resistance decreases as the width of the tire increases (but there is no material advantage gained in making a tire more than 4 inches wide).

(3) It is independent of the speed.

(4) On rough, irregular surfaces, which give rise to constant concussion, it increases with the speed.

The following table shows the relative resistance to traction of various surfaces:

TABLE 1.

Resistance to Traction on Different Road Surfaces.

	Traction Resistance.	
	Pounds per ton.	In terms of load.
Earth road—ordinary condition	50 to 200	$\frac{1}{40}$ to $\frac{1}{10}$
Gravel	50 to 100	$\frac{1}{40}$ to $\frac{1}{20}$
Sand	100 to 200	$\frac{1}{20}$ to $\frac{1}{10}$
Macadam	30 to 100	$\frac{1}{17}$ to $\frac{1}{20}$
Plank Road	30 to 50	$\frac{1}{17}$ to $\frac{1}{40}$
Steel Wheelway	15 to 40	$\frac{1}{133}$ to $\frac{1}{50}$

These coefficients refer to the power required to keep the load in motion. It requires from two to six or eight times as much force to start a load as it does to keep it in motion, at two or three miles per hour. The extra force required to start a load is due in part to the fact that during the stop the wheel may settle into the road surface, in part to the fact that the axle friction at starting is greater than after motion has begun, and further in part to the fact that energy is consumed in accelerating the load.

Resistance to Rolling. This resistance is caused (1) by the wheel penetrating or sinking below the surface of the road, leaving a track or rut behind it. It is equal to the product of the load multiplied by one-third of the semi-chord of the submerged arc of the wheel; and (2) by the wheel striking or colliding with loose or projecting stones, which give a sudden check to the horses, depending upon the height of the obstacle, the momentum destroyed being oftentimes considerable.

The rolling resistance varies inversely as some function of the

diameter of the wheel, as the larger the wheel the less force required to lift it over the obstruction or to roll it up the inclination due to the indentation of the surface.

The power required to draw a wheel over a stone or any obstacle, such as S in Fig. 1, may be thus calculated. Let P represent the power sought, or that which would just balance the weight on the point of the stone, and the slightest increase of which would draw it over. This power acts in the direction C P with the leverage of B C or D E. Gravity, represented by W, resists in the direction C B with the leverage B D. The equation of equilibrium will be $P \times CB = W \times BD$, whence

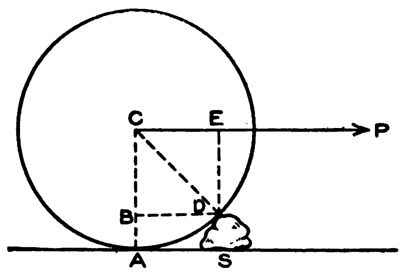

Fig. 1.

$$P = W\frac{BD}{CB} = W\frac{\sqrt{CD^2 - BC^2}}{CD - AB}$$

Let the radius of the wheel = C D = 26 inches, and the height of the obstacle = A B = 4 inches. Let the weight W = 500 pounds, of which 200 pounds may be the weight of the wheel and 300 pounds the load on the axle. The formula then becomes

$$P = 500\frac{\sqrt{676 - 484}}{26 - 4} = 500\frac{13.85}{22} = 314.7 \text{ pounds.}$$

The pressure at the point D is compounded of the weight and the power, and equals

$$W\frac{CD}{CB} = 500 \times \frac{26}{22} = 591 \text{ pounds,}$$

and therefore acts with this great effect to destroy the road in its collision with the stone, in addition there is to be considered the effect of the blow given by the wheel in descending from it. For minute accuracy the non-horizontal direction of the draught and the thickness of the axle should be taken into account. The power required is lessened by proper springs to vehicles, by enlarged wheels, and by making the line of draught ascending.

The mechanical advantage of the wheel in surmounting an obstacle may be computed from the principle of the lever.

Let the wheel, Fig. 2, touch the horizontal line of traction in the point A and meet a protuberance B D. Suppose the line of draught C P to be parallel to A B. Join C D and draw the perpendiculars D E and D F. We may suppose the power to be applied at E and the weight at F, and the action is then the same as the bent lever E D F turning round the fulcrum at D. Hence P : W :: F D : D E. But F D : D E :: tan F C D : 1, and tan F C D = tan 2 (D A B); therefore P = W tan 2 (D A B). Now it is obvious that the angle D A B increases as the radius of the circle diminishes; and therefore, the weight W being constant, the power required to overcome an obstacle of given height is diminished when the diameter is increased. Large wheels are therefore the best adapted for surmounting inequalities of the road.

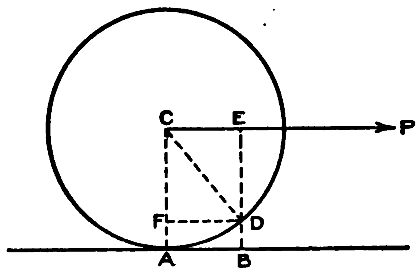

Fig. 2.

There are, however, circumstances which provide limits to the height of the wheels of vehicles. If the radius A C exceeds the height of that part of the horse to which the traces are attached, the line of traction C P will be inclined to the horse, and part of the power will be exerted in pressing the wheel against the ground. The best average size of wheels is considered to be about 6 feet in diameter.

Wheels of large diameter do less damage to a road than small ones, and cause less draught for the horses.

With the same load, a two-wheeled cart does far more damage than one with four wheels, and this because of their sudden and irregular twisting motion in the trackway.

Grade Resistance is due to the action of gravity, and is the same on good and bad roads. On level roads its effect is immaterial, as it acts in a direction perpendicular to the plane of the horizon, and neither accelerates nor retards motion. On inclined roads it offers considerable resistance, proportional to the steepness of the incline.

The resistance due to gravity on any incline in pounds per ton is equal to

$$\frac{2000}{\text{rate of grade}}.$$

The following table shows the resistance due to gravity on different grades.

TABLE 2.

Resistance Due to Gravity on Different Inclinations.

Grade 1 in	20	30	40	50	60	70	80	90	100	200	300	400
Rise in feet per mile ...	264	176	132	105	88	75	66	58	52	26	17	13
Resistance in lb. per ton .	112	74½	56	45	38	32	28	25	22	11¼	7½	5½

The additional resistance caused by inclines may be investigated in the following manner: Suppose the whole weight to be borne on one pair of wheels, and that the tractive force is applied in a direction parallel to the surface of the road.

Let A B in Fig. 3 represent a portion of the inclined road, C being a vehicle just sustained in its position by a force acting in the direction C D. It is evident that the vehicle is kept in its position by three forces; namely, by its own weight W acting in the vertical direction C F, by the force F applied in the direction C D parallel to the surface of the road, and by the pressure P which the vehicle exerts against the surface of the road acting in the direction C E perpendicular to same. To determine the relative magnitude of these three forces, draw a horizontal line A G and the vertical one B G; then, since the two lines C F and B G are parallel and are both cut by the line A B, they must make the two angles C F E and A B G equal; also the two angles C E F and A G B are equal; therefore, the remaining angles F C E and B A G are equal, and the two triangles C F E and A B G are similar. And as the three sides of the former are proportional to the three forces by which the vehicle is sustained, so also are the three sides of the latter; namely, A B or the length of the road is proportional to W, or the weight of the vehicle; B G,

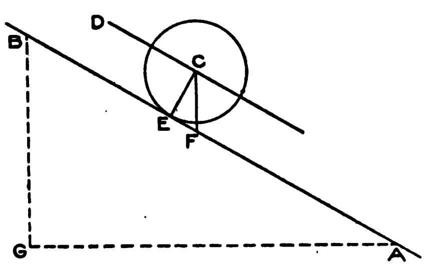

Fig. 3.

or the vertical rise in the same, to F, or the force required to sustain the vehicle on the incline; and A G, or the horizontal distance in which the rise occurs, to P, or the force with which the vehicle presses upon the surface of the road. Therefore,

$$W : AB :: F : GB,$$

and

$$W : AB :: P : AG.$$

If to A G such a value be assigned that the vertical rise of the road is exactly one foot, then

$$F = \frac{W}{AB} = \frac{W}{\sqrt{AG^2 + 1}} = W \cdot \sin A$$

and

$$P = \frac{W \cdot AG}{AB} = \frac{W \cdot AG}{\sqrt{AG^2 + 1}} = W \cdot \cos A,$$

in which A is the angle B A G.

To find the force requisite to sustain a vehicle upon an inclined road (the effects of friction being neglected), divide the weight of the vehicle and its load by the inclined length of the road, the vertical rise of which is one foot, and the quotient is the force required.

To find the pressure of a vehicle against the surface of an inclined road, multiply the weight of the loaded vehicle by the horizontal length of the road, and divide the product by the inclined length of the same; the quotient is the pressure required.

The force with which a vehicle presses upon an inclined road is always less than its actual weight; the difference is so small that, unless the inclination is very steep, it may be taken equal to the weight of the loaded vehicle.

To find the resistance to traction in passing up or down an incline, ascertain the resistance on a level road having the same surface as the incline, to which add, if the vehicle ascends, or subtract, if it descends, the force requisite to sustain it on the incline; the sum or difference, as the case may be, will express the resistance.

Tractive Power and Gradients. The necessity for easy grades is dependent upon the power of the horse to overcome the resistance to motion composed of the four forces, friction, collision, gravity, and the resistance of the air.

All estimates on the tractive power of horses must to a certain

extent be vague, owing to the different strengths and speeds of animals of the same kind, as well as to the extent of their training to any particular kind of work.

The draught or pull which a good average horse, weighing 1,200 pounds, can exert on a level, smooth road at a speed of 2½ miles per hour is 100 pounds, equivalent to 22,000 foot-pounds per minute, or 13,200,000 foot-pounds per day of 10 hours.

The tractive power diminishes as the speed increases and, perhaps, within certain limits, say from ¾ to 4 miles per hour, nearly in inverse proportion to it. Thus the average tractive force of a horse, on a level, and actually pulling for 10 hours, may be assumed approximately as follows:

TABLE 3.

Tractive Power of Horses at Different Velocities.

Miles per hour.	Tractive Force. Lb.	Miles per hour.	Tractive Force. Lb.
¾	333.33	2¼	111.11
1	250	2½	100
1¼	200	2¾	90.91
1½	166.66	3	83.33
1¾	142.86	3½	71.43
2	125	4	62.50

The work done by a horse is greatest when the velocity with which he moves is ⅛ of the greatest velocity with which he can move when unloaded; and the force thus exerted is 0.45 of the utmost force that he can exert at a dead pull.

The traction power of a horse may be increased in about the same proportion as the time is diminished, so that when working from 5 to 10 hours, on a level, it will be about as shown in the following table:

TABLE 4.

Hours per day	Traction (pounds)	Hours per day	Traction (pounds)
10	100	7	146$\frac{6}{7}$
9	111$\frac{1}{9}$	6	166$\frac{1}{3}$
8	125	5	200

The tractive power of teams is about as follows

1 horse		= 1
2 horses	0.95×2	= 1.90
3 "	0.85×3	= 2.55
4 "	0.80×4	= 3.20

Loss of Tractive Power on Inclines. In ascending inclines a horse's power diminishes rapidly; a large portion of his strength is expended in overcoming the resistance of gravity due to his own weight and that of the load. Table 5 shows that as the steepness of the grade increases the efficiency of both the horse and the road surface diminishes; that the more of the horse's energy is expended in overcoming gravity the less remains to overcome the surface resistance.

TABLE 5.

Effects of Grades Upon the Load a Horse can Draw on Different Pavements.

Grade.	Earth.	Broken Stone.	Stone Blocks.	Asphalt.
Level	1.00	1.00	1.00	1.00
1 : 100	.80	.66	.72	.41
2 : 100	.66	.50	.55	.25
3 : 100	.55	.40	.44	.18
4 : 100	.47	.33	.36	.13
5 : 100	.41	.29	.30	.10
10 : 100	.26	.16	.14	.04
15 : 100	.10	.05	.07	...
20 : 100	.04	...	.03	...

Table 6 shows the gross load which an average horse, weighing 1,200 pounds, can draw on different kinds of road surfaces, on a level and on grades rising five and ten feet per one hundred feet.

TABLE 6.

Description of Surface.	Level.	5 per cent grade.	10 per cent grade.
Asphalt	13,216	....	....
Broken stone (best condition)	6,700	1,840	1,060
" " (slightly muddy)	4,700	1,500	1,000
" " (ruts and mud)	3,000	1,390	890
" " (very bad condition)	1,840	1,040	740
Earth (best condition)	3,600	1,500	930
" (average condition)	1,400	900	660
" (moist but not muddy)	1,100	780	600
Stone-block pavement (dry and clean)	8,300	1,920	1,090
" " " (muddy)	6,250	1,800	1,040
Sand (wet)	1,500	675	390
" (dry)	1,087	445	217

The decrease in the load which a horse can draw upon an incline is not due alone to gravity; it varies with the amount of foothold

afforded by the road surface. The tangent of the angle of inclination should not be greater than the coefficient of tractional resistance; therefore it is evident that the smoother the road surface, the easier should be the grade. The smoother the surface the less the foothold, and consequently the load.

The loss of tractive power on inclines is greater than any investigation will show; for, besides the increase of draught caused by gravity, the power of the horse is much diminished by fatigue upon a long ascent, and even in greater ratio than man, owing to its anatomical formation and great weight. Though a horse on a level is as strong as five men, on a grade of 15 per cent, it is less strong than three; for three men carrying each 100 pounds will ascend such a grade faster and with less fatigue than a horse with 300 pounds.

A horse can exert for a short time twice the average tractive pull which he can exert continuously throughout the day's work; hence, so long as the resistance on the incline is not more than double the resistance on the level, the horse will be able to take up the full load which he is capable of drawing.

Steep grades are thus seen to be objectionable, and particularly so when a single one occurs on an otherwise comparatively level road, in which case the load carried over the less inclined portions must be reduced to what can be hauled up the steeper portion.

The bad effects of steep grades are especially felt in winter, when ice covers the roads, for the slippery condition of the surface causes danger in descending, as well as increased labor in ascending; the water of rains also runs down the road and gulleys it out, destroying its surface, thus causing a constant expense for repairs. The inclined portions are subject to greater wear from horses ascending, thus requiring thicker covering than the more level portions, and hence increasing the cost of construction.

It will rarely be possible, except in a flat or comparatively level country, to combine easy grades with the best and most direct route. These two requirements will often conflict. In such a case, increase the length. The proportion of this increase will depend upon the friction of the covering adopted. But no general rule can be given to meet all cases as respects the length which may thus be added, for the comparative time occupied in making the journey forms an

important element in any case which arises for settlement. Disregarding time, the horizontal length of a road may be increased to avoid a 5 per cent grade, seventy times the height.

Table 7 shows, for most practical purposes, the force required to draw loaded vehicles over inclined roads. The first column expresses the rate of inclination; the second, the pressure on the plane in pounds per ton; the third, the tendency down the plane (or force required to overcome the effect of gravity) in pounds per ton; the fourth, the force required to haul one ton up the incline; the fifth, the length of level road which would be equivalent to a mile in length of the inclined road—that is, the length which would require the same motive power to be expended in drawing the load over it, as would be necessary to draw over a mile of the inclined road; the sixth, the maximum load which an average horse weighing 1,200 pounds can draw over such inclines, the friction of the surface being taken at $\frac{1}{50}$ of the load drawn.

TABLE 7.

Rate of grade. Feet per 100 feet.	Pressure on the plane in lb. per ton.	Tendency down the plane in lb. per ton.	Power in lb. required to haul one ton up the plane.	Equivalent length of level road. Miles.	Maximum load in lb. which a horse can haul.
0.0	2240	.00	45.00	1.000	6270
0.25	2240	5.60	50.60	1.121	5376
0.50	2240	11.20	56.20	1.242	4973
0.75	2240	16.80	61.80	1.373	4490
1.	2240	22.40	67.40	1.500	4145
1.25	*2240	28.00	73.00	1.622	3830
1.50	2240	33.60	78.60	1.746	3584
1.75	2240	39.20	84.20	1.871	3290
2	2240	45.00	90.00	2.000	3114
2.25	2240	50.40	95.40	2.120	2935
2.50	2240	56.00	101.00	2.244	2725
2.75	2240	61.33	106.33	2.363	2620
3	2239	67.20	112.20	2.484	2486
4	2238	89.20	134.20	2.982	2083
5	2237	112.00	157.00	3.444	1800
6	2233	134.40	179.40	3.986	1568
7	2232	156.80	201.80	4.844	1367
8	2232	179.20	224.20	4.982	1235
9	2231	201.60	246.60	5.840	1125
10	2229	224.00	269.00	5.977	1030

* Near enough for practice; actually 2239.888.
Pressure on the plane = weight × nat cos of angle of plane.

Axle Friction. The resistance of the hub to turning on the axle is the same as that of a journal revolving in its bearing, and has

nothing to do with the condition of the road surface. The coefficient of journal friction varies with the material of the journal and its bearing, and with the lubricant. It is nearly independent of the velocity, and seems to vary about inversely as the square root of the pressure. For light carriages when loaded, the coefficient of friction is about 0.020 of the weight on the axle; for the ordinary thimble-skein wagon when loaded, it is about 0.012. These coefficients are for good lubrication; if the lubrication is deficient, the axle friction is two to six times as much as above.

The traction power required to overcome the above axle friction for carriages of the usual proportions is about 3 to 3½ lb. per ton of the weight on the axle; and for truck wagons, which have medium sized wheels and axles, is about 3½ to 4½ lb. per ton.

Resistance of the Air. The resistance arising from the force of the wind will vary with the velocity of the wind, with the velocity of the vehicle, with the area of the surface acted upon, and also with the angle of incidence of direction of the wind with the plane of the surface.

The following table gives the force per square foot for various velocities:

TABLE 8.

Velocity of wind in miles per hour.	Force in lbs. per sq. ft.	Description.
15	1.107	Pleasant Breeze
20	1.968	Brisk Gale
25	3.075	
30	4.428	High Wind
35	6.027	
40	7.872	Very High Wind
45	9.963	
50	12.300	Storm

Effect of Springs on Vehicles. Experiments have shown that vehicles mounted on springs materially decrease the resistance to traction, and diminish the wear of the road, especially at speeds beyond a walking pace. Going at a trot, they were found not to cause more wear than vehicles without springs at a walk, all other conditions being similar. Vehicles with springs improperly fixed cause considerable concussion, which in turn destroys the road covering.

LOCATION OF COUNTRY ROADS.

The considerations governing the location of country roads are dependent upon the commercial condition of the country to be traversed. In old and long-inhabited sections the controlling elements will be the character of the traffic to be accommodated. In such a section, the route is generally predetermined, and therefore there is less liberty of a choice and selection than in a new and sparsely settled district, where the object is to establish the easiest, shortest, and most economical line of intercommunication according to the physical character of the ground.

Whichever of these two cases may have to be dealt with, the same principle governs the engineer, namely, to so lay out the road as to effect the conveyance of the traffic with the least expenditure of motive power consistent with economy of construction and maintenance.

Economy of motive power is promoted by easy grades, by the avoidance of all unnecessary ascents and descents, and by a direct line; but directness must be sacrificed to secure easy grades and to avoid expensive construction.

Reconnoissance. The selection of the best route demands much care and consideration on the part of the engineer. To obtain the requisite data upon which to form his judgment, he must make a personal reconnoissance of the district. This requires that the proposed route be either ridden or walked over and a careful examination made of the principal physical contours and natural features of the district. The amount of care demanded and the difficulties attending the operations will altogether depend upon the character of the country.

The immediate object of the reconnoissance is to select one or more trial lines, from which the final route may be ultimately determined.

When there are no maps of the section traversed, or when those which can be procured are indefinite or inaccurate, the work of reconnoitering will be much increased.

In making a reconnoissance there are several points which, if carefully attended to, will very considerably lessen the labor and time otherwise required. Lines which would run along the imme-

diate bank of a large stream must of necessity intersect all the tributaries confluent on that bank, thereby demanding a corresponding number of bridges. Those, again, which are situated along the slopes of hills are more liable in rainy weather to suffer from washing away of the earthwork and sliding of the embankments; the others which are placed in valleys or elevated plateaux, when the line crosses the ridges dividing the principal water courses will have steep ascents and descents.

In making an examination of a tract of country, the first point to attract notice is the unevenness or undulations of its surface, which appears to be entirely without system, order, or arrangement; but upon closer examination it will be perceived that one general principle of configuration obtains even in the most irregular countries. The country is intersected in various directions by main water courses or rivers, which increase in size as they approach the point of their discharge. Towards these main rivers lesser rivers approach on both sides, running right and left through the country, and into these, again, enter still smaller streams and brooks. The streams thus divide the hills into branches or spurs having approximately the same direction as themselves, and the ground falls in every direction from the main chain of hills towards the water courses, forming ridges more or less elevated.

The main ridge is cut down at the heads of the streams into depressions called gaps or passes; the more elevated points are called peaks. The water which has fallen upon these peaks is the origin of the streams which have hollowed out the valleys. Furthermore, the ground falls in every direction towards the natural water courses, forming ridges more or less elevated running between them and separating from each other the districts drained by the streams.

The natural water courses mark not only the lowest lines, but the lines of the greatest longitudinal slope in the valleys through which they flow.

The direction and position of the principal streams give also the direction and approximate position of the high ground or ridges which lie between them.

The positions of the tributaries to the larger stream generally indicate the points of greatest depression in the summits of the ridges,

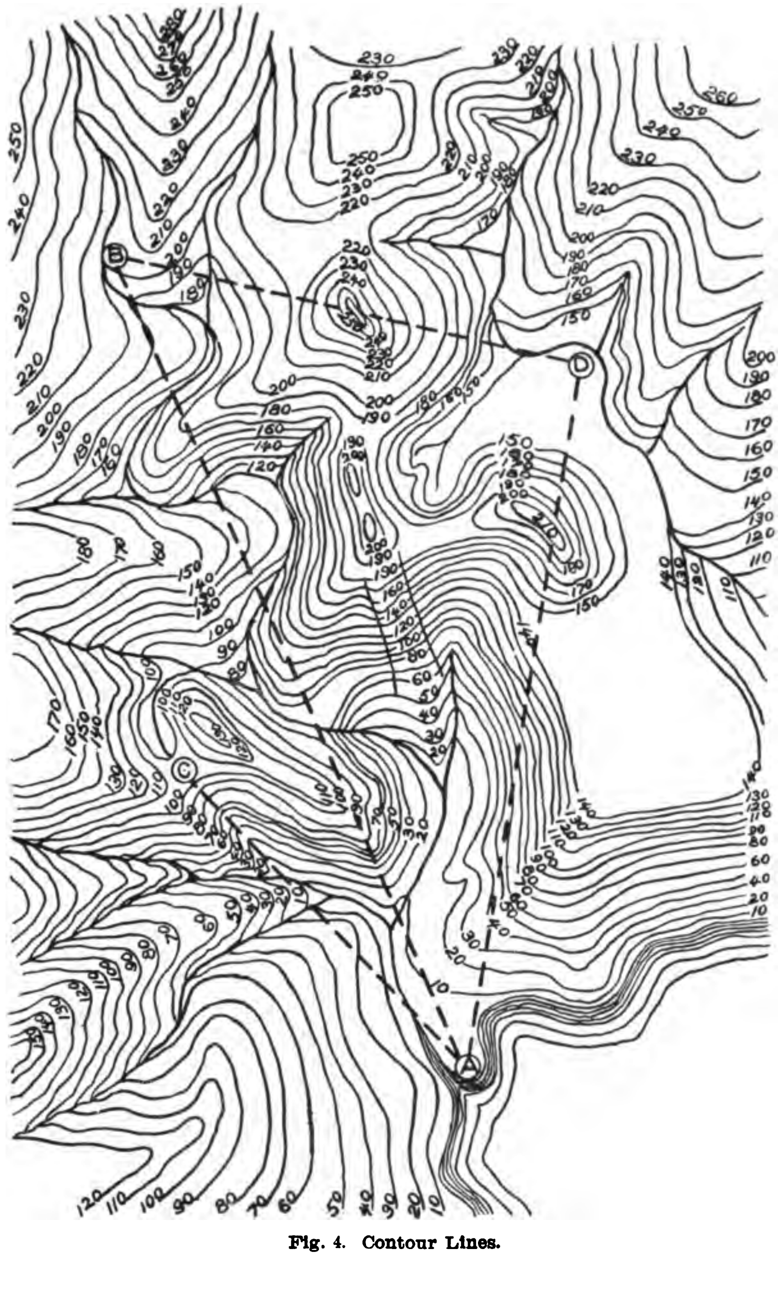

Fig. 4. Contour Lines.

and therefore the points at which lateral communication across the high ground separating contiguous valleys can be most readily made.

The instruments employed in reconnoitering, are: The compass, for ascertaining the direction; the aneroid barometer, to fix the approximate elevation of summits, etc.; and the hand level, to ascertain the elevation of neighboring points. If a vehicle can be used, an odometer may be added, but distances can usually be guessed or ascertained by time estimates or otherwise, closely enough for preliminary purposes. The best maps obtainable and traveling companions who possess a local knowledge of the country, together with the above outfit is all that will be necessary for the first inspection.

The reconnoissance being completed, instrumental surveys of the routes deemed most advantageous should be made. When the several lines are plotted to the same scale, a good map can be prepared from which the exact location of the road can be determined.

In making the preliminary surveys the topographical features should be noted for a convenient distance to the right and the left of the line, and all prominent points located by compass bearings. The following data should also be obtained: the importance, magnitude, and direction of all streams and roads crossed; the character of the material to be excavated or available for embankments, the position of quarries and gravel pits, and the modes of access thereto; and all other information that may effect a selection.

Topography. There are various methods of delineating upon paper the irregularities of the surface of the ground. The method of most utility to the engineer is that by means of "contour lines." These are fine lines traced through the points of equal level over the surface surveyed, and denote that the level of the ground throughout the whole of their course is identical; that is to say, that every part of the ground over which the line passes is at a certain height above a known fixed point termed the datum, this height being indicated by the figures written against the line.

The intervals between the lines vertically are equal and may be 1, 3, 5, 10 or more feet apart; where the surface is very steep they lie close together. These lines by their greater or less distance apart have the effect of shading, and make apparent to the eye, the undulations and irregularities in the surface of the country.

Fig. 4 shows an imaginary tract of country, the physical features of which are shown by contour lines.

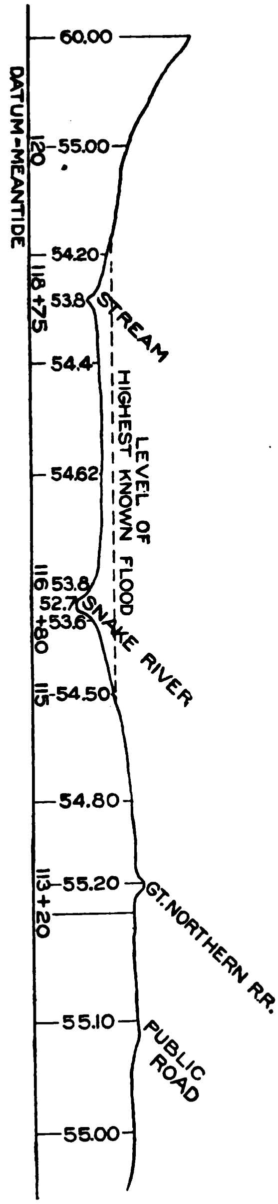

Fig. 5. Preliminary Profile.

Map. The map should show the lengths and direction of the different portions of the line, the topography, rivers, water courses, roads, railroads, and other matters of interest, such as town and county lines, dividing lines between property, timbered and cultivated lands, etc.

Any convenient scale may be adopted; 400 feet to an inch will be found the most useful.

Memoir. The descriptive memoir should give with minuteness all information, such as the nature of the soil, character of the several excavations whether earth or rock, and such particular features as cannot be clearly shown upon the map or profile.

Special information should be given regarding the rivers crossed, as to their width, depth at highest known flood, velocity of current, character of banks and bottom, and the angle of skew which the course makes with the line of the road.

Levels. Levels should be taken along the course of each line, usually at every 100 feet, or at closer intervals, depending upon the nature of the country.

In taking the levels, the heights of all existing roads, railroads, rivers, or canals should be noted. "Bench marks" should be established at least every half mile, that is, marks made on any fixed object, such as a gate post, side of a house, or, in the absence of these, a cut made on a large tree. The height and exact

description of each bench mark should be recorded in the level book.

Cross Levels. Wherever considered necessary levels at right angle to the center line should be taken. These will be found useful in showing what effect a deviation to the right or left of the surveyed line would have. Cross levels should be taken at the intersection of all roads and railroads to show to what extent, if any, these levels will have to be altered to suit the levels of the proposed road.

Profile. A profile is a longitudinal section of the route, made from the levels. Its horizontal scale should be the same as that of the map; the vertical scale should be such as will show with distinctness the inequalities of the ground.

Fig. 5 shows the manner in which a profile is drawn and the nature of the information to be given upon it.

Bridge Sites. The question of choosing the site of bridges is an important one. If the selection is not restricted to a particular point, the river should be examined for a considerable distance above and below what would be the most convenient point for crossing; and if a better site is found, the line of the road must be made subordinate to it. If several practicable crossings exist, they must be carefully compared in order to select the one most advantageous. The following are controlling conditions: (1) Good character of the river bed, affording a firm foundation. If rock is present near the surface of the river bed, the foundation will be easy of execution and stability and economy will be insured. (2) Stability of river banks, thus securing a permanent concentration of the waters in the same bed. (3) The axis of the bridge should be at right angles to the direction of the current. (4) Bends in rivers are not suitable localities and should be avoided if possible. A straight reach above the bridge should be secured if possible.

Final Selection. In making the final selection the following principles should be observed as far as practicable.

(*a*) To follow that route which affords the easiest grades. The easiest grade for a given road will depend on the kind of covering adopted for its surface.

(*b*) To connect the places by the shortest and most direct route commensurate with easy grades.

(*c*) To avoid all unnecessary ascents and descents. When a

road is encumbered with useless ascents, the wasteful expenditure of power is considerable.

(*d*) To give the center line such a position, with reference to the natural surface of the ground, that the cost of construction shall be reduced to the smallest possible amount.

(*e*) To cross all obstacles (where structures are necessary) as nearly as possible at right angles. The cost of skew structures increases nearly as the square of the secant of the obliquity.

(*f*) To cross ridges through the lowest pass which occurs.

(*g*) To cross either under or over railroads; for grade crossings mean danger to every user of the highway.

Examples of Cases to be Treated. In laying out the line of a road, there are three cases which may have to be treated, and each of these is exemplified in the contour map, Fig. 4. First, the two places to be connected, as the towns A and B on the plan, may be both situated in the same valley, and upon the same side of it; that is, they are not separated from each other by the main stream which drains the valley. This is the simplest case. Secondly, although both in the same valley, the two places may be on opposite sides of the valley, as at A and C, being separated by the main river. Thirdly, they may be situated in different valleys, separated by an intervening ridge of ground more or less elevated, as at A and D. In laying out an extensive line of road, it frequently happens that all these cases have to be dealt with.

The most perfect road is that of which the course is perfectly straight and the surface practically level; and, all other things being the same, the best road is that which answers nearest to this description.

Now, in the first case, that of the two towns situated on the same side of the main valley, there are two methods which may be pursued in forming a communication between them. A road following the direct line between them, shown by the thick dotted line A B, may be made, or a line may be adopted which will gradually and equally incline from one town to another, supposing them to be at different levels; or, if they are on the same level, the line should keep at that level throughout its entire course, following all the sinuosities and curves which the irregular formation of the country may render

necessary for the fulfillment of these conditions. According to the first method, a level or uniformly inclined road might be made from one to the other; this line would cross all the valleys and streams which run down to the main river, thus necessitating deep cuttings, heavy embankments, and numerous bridges; or these expensive works might be avoided by following the sinuosities of the valley. When the sides of the main valley are pierced by numerous ravines with projecting spurs and ridges intervening, instead of following the sinuosities, it will be found better to make a nearly straight line cutting through the projecting points in such a way that the material excavated should be just sufficient to fill the hollows.

Of all these, the best is the straight or uniformly inclined, or level road, although at the same time it is the most expensive. If the importance of the traffic passing between the places is not sufficient to warrant so great an outlay, it will become a matter of consideration whether the course of the road should be kept straight, its surface being made to undulate with the natural face of the country; or whether, a level or equally inclined line being adopted, the course of the road should be made to deviate from the direct line, and follow the winding course which such a condition is supposed to necessitate.

In the second case, that of two places situated on opposite sides of the same valley, there is, in like manner, the choice of a perfectly straight line to connect them, which would probably require a big embankment if the road was kept level, or steep inclines if it followed the surface of the country; or by winding the road, it may be carried across the valley at a higher point, where, if the level road be taken, the embankment would not be so high, or, if kept on the surface, the inclination would be reduced.

In the third case, there is, in like manner, the alternative of carrying the road across the intervening ridge in a perfectly straight line, or of deviating it to the right and left, and crossing the ridge at a point where the elevation is less.

The proper determination of the question which of these courses is the best under certain circumstances involves a consideration of the comparative advantages and disadvantages of inclines and curves. What additional increase in the length of a road would be equivalent to a given inclined plane upon it; or conversely, what

inclination might be given to a road as an equivalent to a given decrease in its length? To satisfy this question, the comparative force required to draw different vehicles with given loads must be known, both upon level and variously inclined roads.

The route which will give the most general satisfaction consists in following the valleys as much as possible and rising afterward by gentle grades. This course traverses the cultivated lands, regions studded with farmhouses and factories. The value of such a line is much more considerable than that of a route by the ridges. The water courses which flow down to the main valley are, it is true, crossed where they are the largest and require works of large dimensions, but also they are fewer in number.

Intermediate Towns. Suppose that it is desired to form a road between two distant towns, A and B, Fig. 6, and let us for the present neglect altogether the consideration of the physical features of the intervening country, assuming that it is equally favorable whichever line we select. Now at first sight, it would appear that under such circumstances a perfectly straight line drawn from one town to the other would be the best that could be chosen. On more careful examination however, of the locality, we may find that there is a third town, C, situated somewhat on one side of the straight line which we have drawn from A to B; and although our primary object is to connect only the two latter, that it would nevertheless be of considerable service if the whole of the three towns were put into mutual connection with each other.

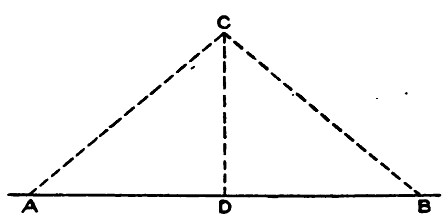

Fig. 6.

This may be effected in three different ways, any one of which might, under the circumstances, be the best. In the first place, we might, as originally suggested, form a straight road from A to B, and in a similar manner two other straight roads from A to C, and from B to C, and this would be the most perfect way of effecting the object in view, the distance between any of the two towns being reduced to the least possible. It would, however, be attended with

considerable expense, and it would be requisite to construct a much greater length of road than according to the second plan, which would be to form, as before, a straight road from A to B, and from C to construct a road which should join the former at a point D, so as to be perpendicular to it. The traffic between A or B and C would proceed to the point D and then turn off to C. With this arrangement, while the length of the roads would be very materially decreased, only a slight increase would be occasioned in the distance between C and the other two towns. The third method would be to form only the two roads A C and C B, in which case the distance between A and B would be somewhat increased, while that between A C or B and C would be diminished, and the total length of road to be constructed would also be lessened.

As a general rule it may be taken that the last of these methods is the best and most convenient for the public; that is to say, that if the physical character of the country does not determine the course of the road, it will generally be found best not to adopt a perfectly straight line, but to vary the line so as to pass through all the principal towns near its general course.

Mountain Roads. The location of roads in mountainous countries presents greater difficulties than in an ordinary undulating country; the same latitude in adopting undulating grades and choice of position is not permissible, for the maximum must be kept before the eye perpetually. A mountain road has to be constructed on the maximum grade or at grades closely approximating it, and but one fixed point can be obtained before commencing the survey, and that is the lowest pass in the mountain range; from this point the survey must be commenced. The reason for this is that the lower slopes of the mountain are flatter than those at their summit; they cover a larger area, and merge into the valley in diverse undulations. So that a road at a foot of a mountain may be carried at will in the desired direction by more than one route, while at the top of a mountain range any deviation from the lowest pass involves increased length of line. The engineer having less command of the ground, owing to the reduced area he has to deal with and the greater abruptness of the slopes, is liable to be frustrated in his attempt to get his line carried in the desired direction.

It is a common practice to run a mountain survey up hill, but this should be avoided. Whenever an acute-angled zigzag is met with on a mountain road near the summit, the inference to be drawn is that the line being carried up hill on reaching the summit was too low and the zigzag was necessary to reach the desired pass. The only remedy in such a case is by a resurvey beginning at the summit and running down hill. This method requires a reversal of that usually adopted. The grade line is first staked out and its horizontal location surveyed afterwards. The most appropriate instrument for this work is a transit with a vertical circle on which the telescope may be set to the angle of the maximum grade.

Loss of Height. Loss of height is to be carefully avoided in a mountain road. By loss of height is meant an intermediate rise in a descending grade. If a descending grade is interrupted by the introduction of an unnecessary ascent, the length of the road will be increased over that due to the continuous grade by the length of the portion of the road intervening between the summit of the rise and the point in the road on a level with that rise—a length which is double that due on the gradient to the height of the rise. For example, if a road descending a mountain rises at some intermediate point to cross over a ridge or spur, and the height ascended amounts to 110 feet before the descent is continued, such a road would be just one mile longer than if the descent had been uninterrupted; for 110 feet is the rise due to a half-mile length at 1:24.

Water on Mountain Roads. Water is needed by the workmen and during the construction of the road; it is also very necessary for the traffic, especially during hot weather; and if the road exceeds 5 miles in length, provision should be made to have it either close to or within easy reach of the road. With a little ingenuity the water from springs above the road, if such exist, can be led down to drinking fountains for men, and to troughs for animals.

In a tropical country it would be a matter for serious consideration if the best line for a mountain road 10 miles in length or upwards, but without water, should not be abandoned in favor of a worse line with a water supply available.

Halting Places. On long lines of mountain roads halting places should be provided at frequent intervals.

Alignment. No rule can be laid down for the alignment of a road; it will depend both upon the character of the traffic on it and upon the "lay of the land." To promote economy of transportation it should be straight; but if straightness is obtained at the expense of easy grades that might have been obtained by deflections and increase in length, it will prove very expensive to the community that uses it.

Where curves are necessary, employ the greatest radius possible and never less than fifty feet. They may be circular or parabolic. The parabolic will be found exceedingly useful for joining tangents of unequal length, and for following contour lines; its curvature being least at its beginning and ending, makes the deviations from a straight line less strongly marked than by a circular arc.

When a curve occurs on an ascent, the grade at that place must be diminished in order to compensate for the additional resistance of the curve.

The width of the wheelway on curves must be increased. This increase should be one-quarter of the width for central angles between 90 and 120 degrees, and one-half for angles between 60 and 90 degrees. Excessive crookedness of alignment is to be avoided, for any unnecessary length causes a constant threefold waste; first, of the interest of the capital expended in making that unnecessary portion; secondly, of the ever recurring expense of repairing it; and thirdly, of the time and labor employed on travelling over it.

The curving road around a hill may be often no longer than the straight one over it, for the latter is straight only with reference to the horizontal plane, while it is curved as to the vertical plane; the former is curved as to the horizontal plane, but straight as to the vertical plane. Both lines curve, and we call the one passing over the hill straight only because its vertical curvature is less apparent to our eyes.

The difference in length between a straight road and one which is slightly curved is very small. If a road between two places ten miles apart were made to curve so that the eye could nowhere see farther than one-quarter of a mile of it at once, its length would exceed that of a straight road between the same points by only about four hundred and fifty feet.

Zigzags. The method of surmounting a height by a series of zigzags or by a series of reaches with practicable curves at the turns, is objectionable.

(1) An acute-angled zigzag obliges the traffic to reverse its direction without affording it convenient room for the purpose. The consequence is that with slow traffic a single train of vehicles is brought to a stand, while if two trains of vehicles travelling in opposite directions meet at the zigzag a block ensues.

(2) With zigzags little progress is made towaros the ultimate destination of the road; height is surmounted, but horizontal distance is increased for which there is no necessity or compensation.

(3) Zigzags are dangerous. In case of a runaway down hill the zigzag must prove fatal.

(4) If the drainage cannot be carried clear of the road at the end of each reach, it must be carried under the road in one reach only to appear again at the next, when a second bridge, culvert, or drain will be required, and so on at the other reaches. If the drainage can be carried clear at the termination of each reach, the lengths between the curves will be very short, entailing numerous zigzag curves, which are expensive to construct and maintain.

Final Location. The route being finally determined upon, it requires to be located. This consists in tracing the line, placing a stake at every 100 feet on the straight portions and at every 50 or 25 feet on the curves. At the tangent point of curves, and at points of compound and reverse curves, a larger and more permanent stake should be placed. Lest those stakes should be disturbed in the process of construction, their exact distance from several points outside of the ground to be occupied by the road should be carefully measured and recorded in the notebook, so that they may be replaced. The stakes above referred to show the position of the center line of the road, and form the base line from which all operations of construction are carried on. Levels are taken at each stake, and cross levels are taken at every change of longitudinal slope.

Construction Profile. The construction or working profile is made from the levels obtained on location. It should be drawn to a horizontal scale of 400 feet to the inch and a vertical scale of 20 feet to the inch. Fig. 7 represents a portion of such a profile. The

figures in column A represent the elevation of the ground at every 100 feet, or where a stake has been driven, above datum. The figures in column B are the elevations of the grade above datum. The figures in column C indicate the depth of cutting or height of fill; they are obtained by taking the difference between the level of the road and the level of the surface of the ground. The straight line

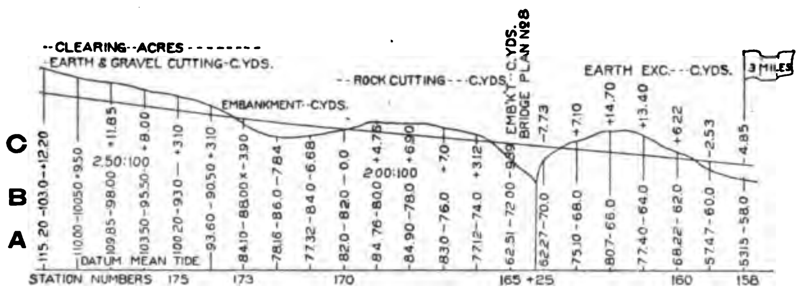

Fig. 7.

at the top represents the grade of the road; the upper surface of the road when finished would be somewhat higher than this, while the given line represents what is termed the sub-grade or formation level. All the dimensions refer to the formation level, to which the surface of the ground is to be formed to receive the road covering.

At all changes in the rate of inclination of the grade line a heavier vertical line should be drawn.

Gradient. The grade of a line is its longitudinal slope, and is designated by the proportion between its length and the difference of height of its two extremes. The ratio of these two qualities gives it its name; if the road ascends or falls one foot in every twenty feet of its length, it is said to have a grade of 1: 20 or a 5 per cent grade. Grades are of two kinds, maximum and minimum. The maximum is the steepest which is to be permitted and which on no account is to be exceeded. The minimum is the least allowable for good drainage. (For method of designating grades see Table 9).

Determination of Gradients. The maximum grade is fixed by two considerations, one relating to the power expended in ascending, the other to the acceleration in descending the incline.

There is a certain inclination, depending upon the degree of perfection given to the surface of the road, which cannot be exceeded

without a direct loss of tractive power. This inclination is that in descending which, at a uniform speed, the traces slacken, or which causes the vehicles to press on the horses; the limiting inclination within which this effect does not take place is the angle of repose.

TABLE 9.

American method. Feet per 100 feet.	English method.	Feet per mile.	Angle with the horizon.
1/4	1 : 400	13.2	0° 8′ 36″
1/2	1 : 200	26.4	0 17 11
3/4	1 : 150	39.6	0 22 55
1	1 : 100	52.8	0 34 23
1 1/4	1 : 80	66	0 42 58
1 1/2	1 : 66 2/3	79.2	0 51 28
1 3/4	1 : 57 1/4	92.4	1 0 51
2	1 : 50	105.6	1 8 6
2 1/4	1 : 44 1/4	118.8	1 17 39
2 1/2	1 : 40	132	1 25 57
2 3/4	1 : 36 1/8	145.2	1 34 22
3	1 : 33 1/3	158.4	1 43 08
3 1/4	1 : 30 3/4	171.6	1 51 42
3 1/2	1 : 28 1/2	184.8	2 0 16
3 3/4	1 : 26 2/3	198	2 8 51
4	1 : 25	211.2	1 17 26
4 1/4	1 : 23 1/2	224.4	2 26 10
4 1/2	1 : 22 1/4	237.6	2 34 36
4 3/4	1 : 21	250.8	2 43 35
5	1 : 20	264	2 51 44
6	1 : 13 2/3	316.8	3 26 12
7	1 : 14 2/7	369.6	4 0 15
8	1 : 12 1/2	422.4	4 34 26
9	1 : 11 1/9	475.2	5 8 31
10	1 : 10	528	5 42 37

The angle of repose for any given road surface can be easily ascertained from the tractive force required upon a level with the same character of surface. Thus if the force necessary on a level to overcome the resistance of the load is $\frac{1}{40}$ of its weight, then the same fraction expresses the angle of repose for that surface.

On all inclines less steep than the angle of repose a certain amount of tractive force is necessary in the descent as well as in the ascent, and the mean of the two drawing forces, ascending and descending, is equal to the force along the level of the road. Thus on such inclines, as much mechanical force is gained in the descent as is lost in the ascent. From this it might be inferred that when a vehicle passes alternately each way along the road, no real loss is

occasioned by the inclination of the road; such is not, however, practically the fact with animal power, for while it is necessary in the ascending journey to have either a less or a greater number of horses than would be requisite if the road were entirely level, no corresponding reduction can be made in the descending journey. On inclines which are more steep than the angle of repose, the load presses on the horses during their descent, so as to impede their action, and their power is expended in checking the descent of the load; or if this effect be prevented by the use of any form of drag or brake, then the power expended on such a drag or brake corresponds to an equal quantity of mechanical power expended in the ascent, for which no equivalent is obtained in the descent.

The maximum grade for a given road will depend (1) upon the class of traffic that will use it, whether fast and light, slow and heavy, or mixed, consisting of both light and heavy; (2) upon the character of the pavement adopted; and (3) upon the question of cost of construction. Economy of motive power and low cost of construction are antagonistic to each other, and the engineer will have to weigh the two in the balance.

For fast and light traffic the grades should not exceed 2 per cent; for mixed traffic 3 per cent may be adopted; while for slow traffic combined with economy 5 per cent should not be exceeded. This grade is practicable but not convenient.

Minimum Grade. From the previous considerations it would appear that an absolutely level road was the one to be sought for, but this is not so; there is a minimum or least allowable grade which the road must not fall short of, as well as a maximum one which it must not exceed. If the road was perfectly level in its longitudinal direction, its surface could not be kept free from water without giving it so great a rise in its middle as would expose vehicles to the danger of overturning. The minimum grade commonly used is 1 per cent.

Undulating Grades. From the fact that the power required to move a load at a given velocity on a level road is decreased on a descending grade to the same extent it is increased in ascending the same grade, it must not be inferred that the animal force expended in passing alternately each way over a rising and falling road will gain as much in descending the several inclines as it will lose in ascend-

[illegible] which is not the case. The animal [illegible] sufficient [illegible] power or number, to draw the load over the level portions and up the steepest inclines of the road, and in practice no reduction in the number of horses can be made to correspond with the decreased power required in descending the inclines.

The popular theory that a gentle undulating road is less fatiguing to horses than one which is perfectly level is erroneous. The assertion that the alternations of ascent, descent, and levels call into play different muscles, allowing some to rest while others are exerted, and thus relieving each in turn, is demonstrably false, and contradicted by the anatomical structure of the horse. Since this doctrine is a mere popular error, it should be utterly rejected, not only because false in itself, but still more because it encourages the building of undulating roads, and this increases the labor and cost of transportation upon them.

Level Stretches. On long ascents it is generally recommended to introduce level or nearly level stretches at frequent intervals in order to rest the animals. These are objectionable when they cause loss of height, and animals will be more rested by halting and unharnessing for half an hour than by travelling over a level portion. The only case which justifies the introduction of levels into an ascending road is where such levels will advance the road towards its objective point; where this is the case there will be no loss of either length or height, and it will simply be exchanging a level road below for a level road above.

Establishing the Grade. When the profile of a proposed route has been made, a grade line is drawn upon it (usually in red) in such a manner as to follow its general slope, but to average its irregular elevation and depressions.

If the ratio between the whole distance and the height of the line is less than the maximum grade intended to be used, this line will be satisfactory; but if it be found steeper, the cuttings or the length of the line will have to be increased; the latter is generally preferable.

The apex or meeting point of all curves should be rounded off by a vertical curve, as shown in Fig. 8, thus slightly changing the grade at and near the point of intersection. A vertical curve rarely need extend more than 200 feet each way from that point.

Let A B, B C, be two grades in profile, intersecting at station B, and let A and C be the adjacent stations. It is required to join the

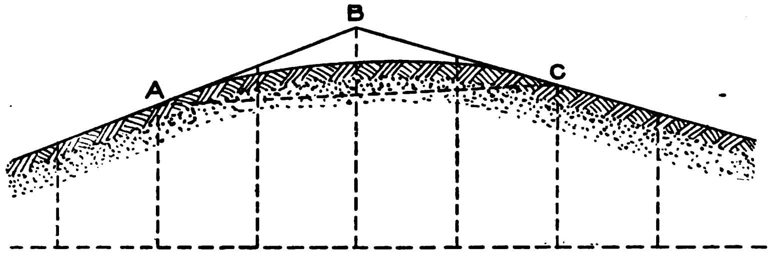

Fig. 8.

grades by a vertical curve extending from A to C. Imagine a chord drawn from A to C. The elevation of the middle point of the chord will be a mean of the elevations of the grade at A and C, and one-half of the difference between this and the elevation of the grade at B will be the middle ordinate of the curve. Hence we have

$$M = \frac{1}{2}\left(\frac{\text{grade A} + \text{grade C}}{2} - \text{grade B}\right),$$

in which M equals the correction in grade for the point B. The correction for any other point is proportional to the square of its distance from A or C. Thus the correction A + 25 is $\frac{1}{16}$ M; at A + 50 it is $\frac{1}{4}$ M; at A + 75 it is $\frac{9}{16}$ M; and the same for corresponding points on the other side of B. The corrections in this case shown are subtractive, since M is negative. They are additive when M is positive, and the curve concave upward.

WIDTH AND TRANSVERSE CONTOUR.

A road should be wide enough to accommodate the traffic for which it is intended, and should comprise a wheelway for vehicles and a space on each side for pedestrians.

The wheelway of country highways need be no wider than is absolutely necessary to accommodate the traffic using it; in many places a track wide enough for a single team is all that is necessary. But the breadth of the land appropriated for highway purposes should be sufficient to provide for all future increase of traffic. The wheelways of roads in rural sections should be double; that is, one portion paved (preferably the center), and the other left with the

[illegible]

of the convexity. Circular arcs, two straight lines joined by a circular arc, and ellipses, all have their advocates.

TABLE 10.

Kind of Surface.		Proportions of the Carriageway. Width.
Earth	Rise at center	$\frac{1}{40}$
Gravel	" " "	$\frac{1}{50}$
Broken Stone	" " "	$\frac{1}{60}$

For country roads a curve of suitable convexity may be obtained as follows: Give $\frac{7}{8}$ of the total rise at $\frac{1}{4}$ the width from the center to the side, and $\frac{5}{8}$ of the total rise at $\frac{1}{2}$ the width (Fig. 9).

Excessive height and convexity of cross-section contract the width of the wheelway, by concentrating the traffic at the center, that being the only part where a vehicle can run upright. The force required to haul vehicles over such cross-sections is increased, be-

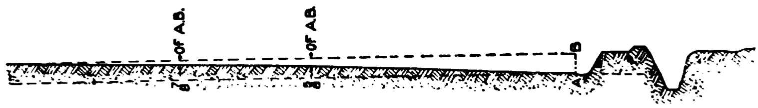

Fig. 9.

cause an undue proportion of the load is thrown upon two wheels instead of being distributed equally over the four. The continual tread of horses' feet in one track soon forms a depression which holds water, and the surface is not so dry as with a flat section, which allows the traffic to distribute itself over the whole width.

Sides formed of straight lines are also objectionable. They wear hollow, retain water, and defeat the object sought by raising the center.

The required convexity should be obtained by rounding the formation surface, and not by diminishing the thickness of the covering at the sides.

Although on hillside and mountain roads it is generally recommended that the surface should consist of a single slope inclining inwards, there is no reason for or advantage gained by this method. The form best adapted to these roads is the same as for a road under ordinary conditions.

With a roadway raised in the center and the rain water draining off to gutters on each side, the drainage will be more effectual and

speedy than if the drainage of the outer half of the road has to pass over the inner half. The inner half of such a road is usually subjected to more traffic than the outer half. If formed of a straight incline, this side will be worn hollow and retain water. The inclined flat section never can be properly repaired to withstand the traffic. Consequently it never can be kept in good order, no matter how constantly it may be mended. It is always below par and when heavy rain falls it is seriously damaged.

DRAINAGE.

In the construction of roads, drainage is of the first importance. The ability of earth to sustain a load depends in a large measure upon the amount of moisture retained by it. Most earths form a good firm foundation so long as they are kept dry, but when wet they lose their sustaining power, becoming soft and incoherent.

The drainage of roadways is of two kinds, viz., surface and subsurface. The first provides for the speedy removal of all water falling on the surface of the road; the second provides for the removal of the underground-water found in the body of the road, a thorough removal of which is of the utmost importance and essential to the life of the road. A road covering placed on a wet undrained bottom will be destroyed by both water and frost, and will always be troublesome and expensive to maintain; perfect subsoil drainage is a necessity and will be found economical in the end even if in securing it considerable expense is required.

The methods employed for securing the subsoil drainage must be varied according to the character of the natural soil, each kind of soil requiring different treatment.

The natural soil may be divided into the following classes: silicious, argillaceous, and calcareous; rock, swamps, and morasses.

The silicious and calcareous soils, the sandy loams and rock, present no great difficulty in securing a dry and solid foundation. Ordinarily they are not retentive of water and therefore require no underdrains; ditches on each side of the road will generally be found sufficient.

The argillaceous soils and softer marls require more care; they retain water and are difficult to compact, except at the surface; and they are very unstable under the action of water and frost.

The drainage of these soils may be effected by transverse drains and deep side ditches of ample width. The transverse drains are placed across the road, not at right angles but in the form of an inverted V with the point directed up hill; the depth at the angle point should not be less than 18 inches below the subgrade surface, and each branch should descend from the apex to the side ditches with a fall of not less than 1 inch in 5 feet. The distance apart of these drains will depend upon the wetness of the soil; in the case of very wet soil they should be at intervals of 15 feet, which may be increased to 25 feet as the ground becomes drier and firmer.

The transverse drains are best formed of unglazed circular tile of a diameter not less than 3 inches, jointed with loose collars. The tiles are made from terra cotta or burnt clay, are porous, and are superior to all other kinds of drains. They carry off the water with greater ease, rarely if ever get choked up, and only require a slight inclination to keep the water moving through them.

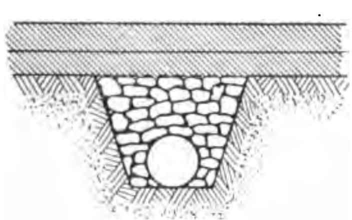

Fig. 10. Tile Drain.

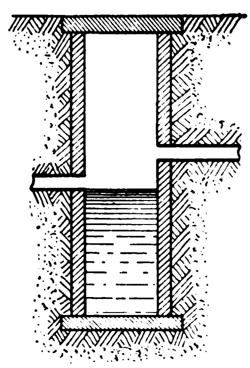

Fig. 11. Silt Basin.

The tiles are made in a variety of forms, as horseshoe, sole, double sole, and round, the name being derived from the shape of the cross-sections. Round tile is superior to all other forms. The inside diameter of these tiles varies from $1\frac{1}{4}$ to 6 inches, but they are manufactured as large as 24 inches. Pieces of the larger pipe serve as collars for the smaller ones. They are made in lengths of 12, 14 and 24 inches, and in thickness of shell from $\frac{1}{4}$ of an inch to 1 inch.

The collar which encircles the joint of the small tile allows a large opening, and at the same time prevents sand and silt from

entering the drain. Perishable material should not be used for jointing. When laid in the ditch they should be held in place by small stones. Connections should be made by proper Y-branches.

The outlets may be formed by building a dwarf wall of brick or stone, whichever is the cheapest or most convenient in the locality. The outlet should be covered with an iron grating to prevent vermin entering the drain pipes, building nests and thus choking up the waterway. (See Fig. 12.)

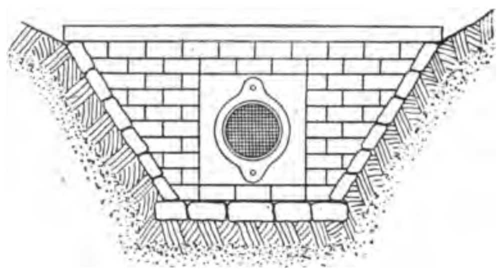

Fig. 12. Outlet.

Silt-basins should be constructed at all junctions and wherever else they may be considered necessary; they may be made from a single 6-inch pipe (Fig. 11) or constructed of brick masonry.

The trenches for the tile should be excavated at least 3 feet wide on top and 12 inches on the bottom. After the tiles are laid the trenches must be filled to subgrade level with round field or cobble stones; stones with angular edges are unsuitable for this purpose. Fine gravel, sand, or soil should not be placed over the drains. Bricks and flat stones may be substituted for the tiles, and the trenches filled as above stated.

As tile drains are more liable to injury from frost than those of either brick or stone, their ends at the side ditches should not in very cold climates be exposed directly to the weather, but may terminate in blind drains, or a few lengths of vitrified clay pipe reaching under the road a distance of about 3 to 4 feet from the inner slope of the ditch.

Another method of draining the roadbed offering security from frost is by one or more rows of longitudinal drains. These drains are placed at equal distances from the side ditches and from each other, and discharge into cross drains placed from 250 to 300 feet

apart, more or less, depending on the contour of the ground. The cross drains into which they discharge should be of ample dimensions. On these longitudinal lines of tiles the introduction of catch basins at intervals of 50 feet will facilitate the removal of the water. These catch basins may be excavated three or more feet square and as deep as the tiles are laid. After the tiles are laid the pit is filled with gravel and small stones.

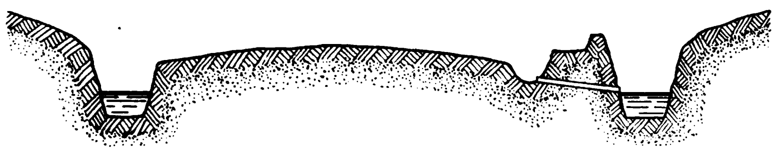

Fig. 13.

Fall of Drains. It is a mistake to give too much fall to small drains, the only effect of which is to produce such a current through them as will wash away or undermine the ground around them, and ultimately cause their own destruction. When a drain is once closed by any obstruction no amount of fall which could be given it will

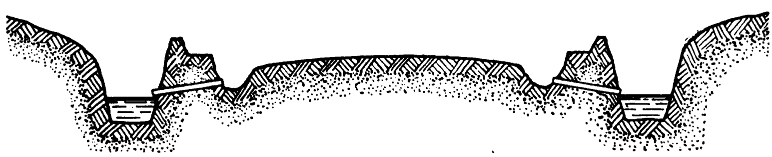

Fig. 14.

again clear the passage. A drain with a considerable current through it is much more likely to be stopped from foreign matter carried into it, which a less rapid stream could not have transported.

A fall of 1 inch in 5 feet will generally be sufficient, and 1 inch in 30 inches should never be exceeded.

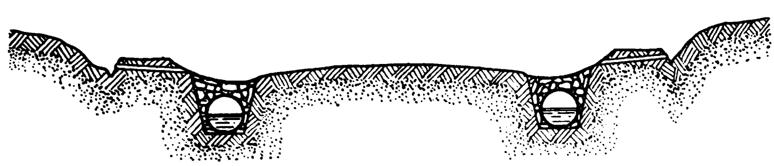

Fig. 15.

Side Ditches are provided to carry away the subsoil water from the base of the road, and the rain water which falls upon its surface; to do this speedily they must have capacity and inclination

proportionate to the amount of water reaching them. The width of the bed should not be less than 18 inches; the depth will vary with circumstances, but should be such that the water surface shall not reach the subgrade, but remain at least 12 inches below the crown of the road. The sides should slope at least $1\frac{1}{2}$ to 1.

The longitudinal inclination of the ditch follows the configuration of the general topography, that is, the lines of natural drainage. When the latter has to be aided artificially, grades from 1 in 500 to 1 in 800 will usually answer.

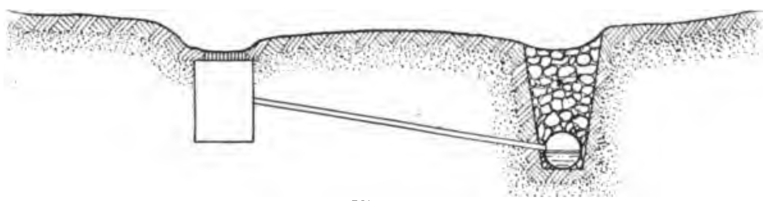

Fig. 16.

In absorbent soil less fall is sufficient, and in certain cases level ditches are permissible. The slopes of the ditches must be protected where the grade is considerable. This can be accomplished by sod revetments, riprapping, or paving.

These ditches may be placed either on the road or land side of the fence. In localities where open ditches are undesirable they may be constructed as shown in Figs. 13 to 17, and may be formed of stone

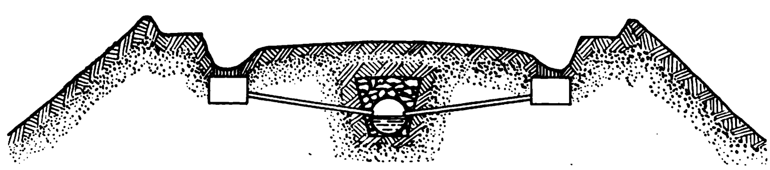

Fig. 17.

or tile pipe, according to the availability of either material. If for any reason two can not be built, build one.

Springs found in the roadbed should be tapped and led into the side ditches.

Drainage of the Surface. The drainage of the roadway surface depends upon the preservation of the cross-section, with regular and uninterrupted fall to the sides, without hollows or ruts in which the water can lie, and also upon the longitudinal fall of the

road. If this is not sufficient the road becomes flooded during heavy rainstorms and melting snow, and is considerably damaged.

The removal of surface water from country roads may be effected by the side ditches, into which, when there are no sidewalks, the water flows directly. When there are sidewalks, gutters are formed between the roadway and footpath, as shown in Figs. 13 to 17, and the water is conducted from these gutters into the side ditches by tile pipes laid under the walks at intervals of about 50 feet. The entrance to these pipes should be protected against washing by a rough stone paving. In the case of covered ditches under the footpath the water must be led into them by first passing through a catch basin. These are small masonry vaults covered with iron gratings to prevent the ingress of stones, leaves, etc. Connection from the catch basin is made by a tile pipe about 6 inches in diameter. The mouth of this pipe is placed a few feet above the bottom of the catch basin, and the space below it acts as a depository for the silt carried by the water, and is cleaned out periodically. The catch basins may be placed from 200 to 300 feet apart. They should be made of dimensions sufficient to convey the amount of water which is liable to flow into them during heavy and continuous rains.

If on inclines the velocity of the water is greater than the nature of the soil will withstand, the gutters will be roughly paved. In all cases, the slope adjoining the footpath should be covered with sod.

A velocity of 30 feet a minute will not disturb clay with sand and stone. 40 feet per minute will move coarse sand. 60 feet a minute will move gravel. 120 feet a minute should move round pebbles 1 inch in diameter, and 180 feet a minute will move angular stones $1\frac{3}{4}$ inches in diameter.

The scour in the gutters on inclines may be prevented by small weirs of stones or fascines constructed by the roadmen at a nominal cost. At junctions and crossroads the gutters and side ditches require careful arrangement so that the water from one road may not be thrown upon another; cross drains and culverts will be required at such places.

Water Breaks to turn the surface drainage into the side ditches should not be constructed on improved roads. They increase the grade and are an impediment to convenient and easy travel. Where

it is necessary that water should cross the road a culvert should be built.

On the side hill or mountain roads catch-water ditches should be cut on the mountain side above the road, to cut off and convey the drainage of the ground above them to the neighboring ravines. The size of these ditches will be determined by the amount of rainfall, extent of drainage from the mountain which they intercept, and by the distances of the ravine water courses on each side.

The inner road gutter should be of ample dimensions to carry off the water reaching it; when in soil, it should be roughly paved with stone. When paving is not absolutely necessary, but it is desirable to arrest the scouring action of running water during heavy rains, stone weirs may be erected across the gutter at convenient intervals. The outer gutter need not be more than 12 inches wide and 9 inches deep. The gutter is formed by a depression in the surface of the road close to the parapet or revetted earthen protection mound. The drainage which falls into this gutter is led off through the parapet, or other roadside protection at frequent intervals. The guard stones on the outside of the road are placed in and across this gutter, just below the drainage holes, so as to turn the current of the drainage into these holes or channels. On straight reaches, with parapet protection, drainage holes with guard stones should be placed every 20 feet apart. Where earthen mounds are used and it may not be convenient to have the drainage holes or channels every 20 feet, the guardstones are to be placed in advance of the gutter to allow the drainage to pass behind them. This drainage is either to be run off at the cross drainage of the road, or to be turned off as before by a guard stone set across the gutter.

At re-entering turns, where the outer side of the road requires particular protection, guard stones should be placed every 4 feet. As all re-entering turns should be protected by parapets, the drainage holes through them may be placed as close together as desired.

Culverts are necessary for carrying under a road the streams it crosses, and also for conveying the surface water collected in the side ditches from the upper side to that side on which the natural water courses lie.

Especial care is required to provide an ample way for the water

to be passed. If the culvert is too small, it is liable to cause a washout, entailing interruption of traffic and cost of repairs, and possibly may cause accidents that will require payment of large sums for damages. On the other hand, if the culvert is made unnecessarily large, the cost of construction is needlessly increased.

The area of waterway required depends (1) upon the rate of rainfall; (2) the kind and condition of the soil; (3) the character and inclination of the surface; (4) the condition and inclination of the bed of the stream; (5) the shape of the area to be drained, and the position of the branches of the stream; (6) the form of the mouth and the inclination of the bed of the culvert; and (7) whether it is permissible to back the water up above the culvert, thereby causing it to discharge under a head.

(1) It is the maximum rate of rainfall during the severest storms which is required in this connection. This varies greatly in different sections of the country.

The maximum rainfall as shown by statistics is about one inch per hour (except during heavy storms), equal to 3,630 cubic feet per acre. Owing to various causes, not more than 50 to 75 per cent of this amount will reach the culvert within the same hour.

Inches of rainfall $\times$ 3,630 = cubic feet per acre.

Inches of rainfall $\times$ 2,323,200 = cubic feet per square mile.

(2) The amount of water to be drained off will depend upon the permeability of the surface of the ground, which will vary greatly with the kind of soil, the degree of saturation, the condition of the cultivation, the amount of vegetation, etc.

(3) The rapidity with which the water will reach the water course depends upon whether the surface is rough or smooth, steep or flat, barren or covered with vegetation, etc.

(4) The rapidity with which the water will reach the culvert depends upon whether there is a well-defined and unobstructed channel, or whether the water finds its way in a broad thin sheet. It the water course is unobstructed and has a considerable inclination, the water may arrive at the culvert nearly as rapidly as it falls; but if the channel is obstructed, the water may be much longer in passing the culvert than in falling.

(5) The area of waterway depends upon the amount of the area

to be drained; but in many cases the shape of this area and the position of the branches of the stream are of more importance than the amount of the territory. For example, if the area is long and narrow, the water from the lower portion may pass through the culvert before that from the upper end arrives; or, on the other hand, if the upper end of the area is steeper than the lower, the water from the former may arrive simultaneously with that from the latter. Again, if the lower part of the area is better supplied with branches than the upper portion, the water from the former will be carried past the culvert before the arrival of that from the latter; or, on the other hand, if the upper part is better supplied with branch water courses than the lower, the water from the whole area may arrive at the culvert at nearly the same time. In large areas the shape of the area and the position of the water courses are very important considerations.

(6) The efficiency of a culvert may be very materially increased by so arranging the upper end that the water may enter into it without being retarded. The discharging capacity of a culvert can be greatly increased by increasing the inclination of its bed, provided the channel below will allow the water to flow away freely after having passed the culvert.

(7) The discharging capacity of a culvert can be greatly increased by allowing the water to dam up above it. A culvert will discharge twice as much under a head of four feet as under a head of one foot. This can be done safely only with a well constructed culvert.

The determination of the values of the different factors entering into the problem is almost wholly a matter of judgment. An estimate for any one of the above factors is liable to be in error from 100 to 200 per cent, or even more, and of course any result deduced from such data must be very uncertain. Fortunately, mathematical exactness is not required by the problem nor warranted by the data. The question is not one of 10 or 20 per cent of increase; for if a 2-foot pipe is sufficient, a 3-foot pipe will probably be the next size, an increase of 225 per cent; and if a 6-foot arch culvert is too small, an 8-foot will be used, an increase of 180 per cent. The real question is whether a 2-foot pipe or an 8-foot arch culvert is needed.

Valuable data on the proper size of any particular culvert may be obtained (1) by observing the existing openings on the same

stream; (2) by measuring, preferably at time of high water, a cross-section of the stream at some narrow place; and (3) determining the height of high water as indicated by drift and the evidence of the inhabitants of the neighborhood.

On mountain roads or roads subjected to heavy rainfall culverts of ample dimensions should be provided wherever required, and it will be more economical to construct them of masonry. In localities where boulders and other debris are likely to be washed down during wet weather, it will be a good precaution to construct catch pools at the entrance of all culverts and cross drains for the reception of such matter. In hard soil or rock these catch pools will be simple well-like excavations, with their bottom two or three feet below the entrance sill or floor of the culvert or drain. Where the soil is soft they should be lined with stone laid dry; if very soft, with masonry. The size of the catch pools will depend upon the width of the drainage works. They should be wide enough to prevent the drains from being injured by falling rocks and stones of a not inordinate size.

The use of catch pools obviates the necessity of building culverts and drains at an angle to the axis of the road. Oblique structures are objectionable, as being longer than if set at right angles and by reason of the acute- and obtuse-angled terminations to their piers, abutments, and coverings.

Materials for Culverts. Culverts may be of stone, brick, vitrified earthenware, or iron pipe. Wood should be absolutely avoided.

For small streams and a limited surface of rainfall either class of pipes, in sizes varying from 12 to 24 inches in diameter, will serve excellently. They are easily laid, and if properly bedded, with the earth tamped about them, are very permanent. Their upper surface should be at least 18 inches below the road surface, and the upper end should be protected with stone paving so arranged that the water can in no case work in around the pipe.

When the flow of water is estimated to be too great for two lines of 24-inch pipes, a culvert is required. If stone abounds, it may be built of large roughly squared stones laid either dry or in mortar. When the span required is more than 5 feet, arch culverts either of stone or brick masonry may be employed. For spans above 15 feet the structure required becomes a bridge.

Earthenware Pipe Culverts. *Construction.* In laying the pipe the bottom of the trench should be rounded out to fit the lower half of the body of the pipe with proper depressions for the sockets. If the ground is soft or sandy, the earth should be rammed carefully, but solidly in and around the lower part of the pipe. The top surface of the pipe should, as a rule, never be less than 18 inches below the surface of the roadway, but there are many cases where pipes have stood for several years under heavy loads with only 8 to 12 inches of earth over them. No danger from frost need be apprehended, provided the culverts are so constructed that the water is carried away from the level end. Ordinary soft drain tiles are not in the least affected by the expansion of frost in the earth around them.

The freezing of water in the pipe, particularly if more than half full, is liable to burst it; consequently the pipe should have a sufficient fall to drain itself, and the outside should be so low that there is no danger of back waters reaching the pipe. If properly drained, there is no danger from frost.

Jointing. In many cases, perhaps in most, the joints are not calked. If this is not done, there is liability of the water being forced out of the joints and washing away the soil from around the pipe. Even if the danger is not very imminent, the joints of the larger pipes, at least, should be calked with hydraulic cement, since the cost is very small compared with the insurance against damage

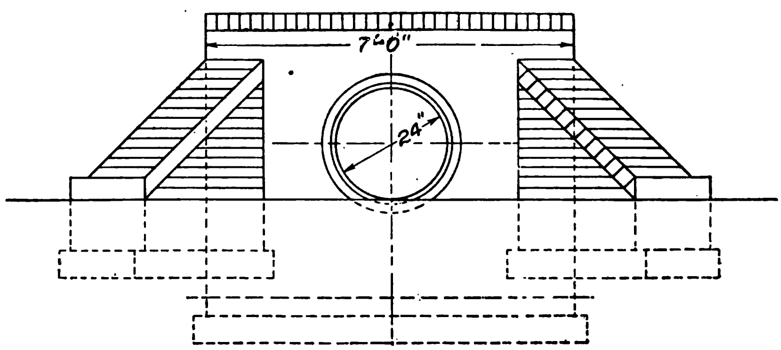

Fig. 18.

thereby secured. Sometimes the joints are calked with clay. Every culvert should be built so that it can discharge water under a head without damage to itself.

Although often omitted, the end sections should be protected with a masonry or timber bulkhead. The foundation of the bulkhead should be deep enough not to be disturbed by frost. In constructing the end wall, it is well to increase the fall near the outlet to allow for a possible settlement of the interior sections. When stone and brick abutments are too expensive, a fair substitute can be made by setting posts in the ground and spiking plank to them. When planks are used, it is best to set them with considerable inclination towards the roadbed to prevent their being crowded outward by the pressure of the embankment. The upper end of the culvert should be so protected that the water will not readily find its way

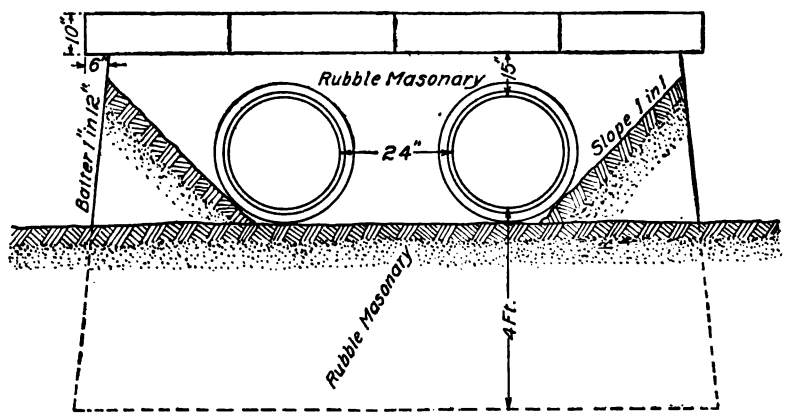

Fig. 19.

along the outside of the pipes, in case the mouth of the culvert should become submerged.

When the capacity of one pipe is not sufficient, two or more may be laid side by side as shown in Fig. 19. Although the two small pipes do not have as much discharging capacity as a single large one of equal cross-section, yet there is an advantage in laying two small ones side by side, since the water need not rise so high to utilize the full capacity of the two pipes as would be necessary to discharge itself through a single one of large size.

Iron Pipe Culverts. During recent years iron pipe has been used for culverts on many prominent railroads, and may be used on roads in sections where other materials are unavailable.

In constructing a culvert with cast-iron pipe the points requiring

particular attention are (1) tamping the soil tightly around the pipe to prevent the water from forming a channel along the outside, and (2) protecting the ends by suitable head walls and, when necessary, laying riprap at the lower end. The amount of masonry required for the end walls depends upon the relative width of the embankment and the number of sections of pipe used. For example, if the embankment is, say, 40 feet wide at the base, the culvert may consist of three 12-foot lengths of pipe and a light end wall near the toe of the bank; but if the embankment is, say, 32 feet wide, the culvert may consist of two 12-foot lengths of pipe and a comparatively heavy end wall well back from the toe of the bank. The smaller sizes of pipe usually come in 12-foot lengths, but sometimes a few 6-foot

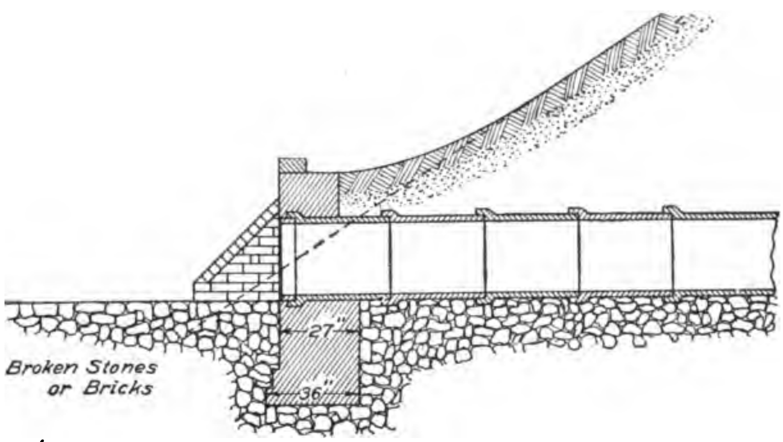

Fig. 20. Section of Pipe Culvert

lengths are included for use in adjusting the length of the culvert to the width of the bank. The larger sizes are generally 6 feet long.

EARTHWORK.

The term "earthwork" is applied to all the operations performed in the making of excavation and embankments. In its widest sense it comprehends work in rock as well as in the looser materials of the earth's crust.

Balancing Cuts and Fills. In the construction of new roads, the formation of the roadbed consists in bringing the surface of the ground to the adopted grade. This grade should be established so as

to reduce the earthwork to the least possible amount, both to render the cost of construction low, and to avoid unnecessary marring the appearance of the country in the vicinity of the road. The most desirable position of the grade line is usually that which makes the amount of cutting and filling equal to each other, for any surplus embankment over cutting must be made up by borrowing, and surplus cutting must be wasted, both of these operations involving additional cost for labor and land.

Inclination of Side Slopes. The proper inclination for the side slopes of cutting and embankments depends upon the nature of the soil, the action of the atmosphere and of internal moisture upon it. For economy the inclination should be as steep as the nature of the soil will permit.

The usual slopes in cuttings are:

Solid rock	1 to 1
Earth and Gravel	$3\frac{1}{2}$ to 1
Clay	3 or 6 to 1
Fine sand	2 or 3 to 1

The slopes of embankment are usually made $1\frac{1}{2}$ to 1.

Form of Side Slopes. The natural, strongest, and ultimate form of earth slopes is a concave curve, in which the flattest portion is at the bottom. This form is very rarely given to the slopes in constructing them; in fact, the reverse is often the case, the slopes being made convex, thus saving excavation by the contractor and inviting slips.

In cuttings exceeding 10 feet in depth the forming of concave slopes will materially aid in preventing slips, and in any case they will

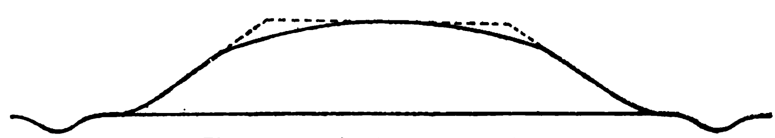

Fig. 21. Cross-Section for Embankment.

reduce the amount of material which will eventually have to be removed when cleaning up. Straight or convex slopes will continue to slip until the natural form is attained.

A revetment or retaining wall at the base of a slope will save excavation.

In excavations of considerable depth, and particularly in soils liable to slips, the slope may be formed in terraces, the horizontal offsets or benches being made a few feet in width with a ditch on the inner side to receive the surface water from the portion of the side slope above them. These benches catch and retain earth that may fall from the slopes above them. The correct forms for the slopes of embankment and excavation are shown in Figs. 21 and 22.

Covering of Slopes. It is not usual to employ any artificial means to protect the surface of the side slopes from the action of the weather; but it is a precaution which in the end will save much labor

Fig. 22. Cross-Section for Excavation.

and expense in keeping the roadways in good order. The simplest means which can be used for this purpose consists in covering the slopes with good sods, or else with a layer of vegetable mould about four inches thick, carefully laid and sown with grass seed. These means are amply sufficient to protect the side slopes from injury when they are not exposed to any other cause of deterioration than the wash of the rain and the action of frost on the ordinary moisture retained by the soil.

A covering of brushwood or a thatch of straw may also be used with good effect; but from their perishable nature they will require frequent renewal and repairs.

Where stone is abundant a small wall of stone laid dry may be constructed at the foot of the slopes to prevent any wash from them being carried into the ditches.

Shrinkage of Earthwork. All materials when excavated increase in bulk, but after being deposited in banks subside or shrink (rock excepted) until they occupy less space than in the pit from which excavated.

Rock, on the other hand, increases in volume by being broken up, and does not settle again into less than its original bulk. The increase may be taken at 50 per cent.

The shrinkage in the different materials is about as follows:

Gravel	8 per cent
Gravel and sand	9 " "
Clay and clay earths	10 " "
Loam and light sandy earths	12 " "
Loose vegetable soil	15 " "
Puddled clay	25 " "

Thus an excavation of loam measuring 1,000 cubic yards will form only about 880 cubic yards of embankment, or an embankment of 1,000 cubic yards will require about 1,120 cubic yards measured in excavation to make it. A rock excavation measuring 1,000 yards will make from 1,500 to 1,700 cubic yards of embankment, depending upon the size of the fragments.

The lineal settlement of earth embankments will be about in the ratio given above; therefore either the contractor should be instructed in setting his poles to guide him as to the height of grade on an earth embankment to add the required percentage to the fill marked on the stakes, or the percentage may be included in the fill marked on the stakes. In rock embankments this is not necessary.

Classification of Earthwork. Excavation is usually classified under the heads *earth, hardpan, loose rock,* and *solid rock.* For each of these classes a specific price is usually agreed upon, and an extra allowance is sometimes made when the haul or distance to which the excavated material is moved exceeds a given amount.

The characteristics which determine the classes to which a given material belongs are usually described with clearness in the specifications, as:

Earth will include loam, clay, sand, and loose gravel.

Hardpan will include cemented gravel, slate, cobbles, and boulders containing less than one cubic foot, and all other matters of an earthy nature, however compact they may be.

Loose rock will include shale, decomposed rock, boulders, and detached masses of rock containing not less than three cubic feet, and all other matters of a rock nature which may be loosened with a pick, although blasting may be resorted to in order to expedite the work.

Solid rock will include all rock found in place in ledges and

masses, or boulders measuring more than three cubic feet, and which can only be removed by blasting.

Prosecution of Earthwork. No general rule can be laid down for the exact method of carrying on an excavation and disposing of the excavated material. The operation in each case can only be determined by the requirements of the contract, character of the material, magnitude of the work, length of haul, etc.

Formation of Embankments. Where embankments are to be formed of less than two feet in height, all stumps, weeds, etc. should be removed from the space to be occupied by the embankment. For embankments exceeding two feet in height stumps need only be close cut. Weeds and brush, however, ought to be removed and if the surface is covered with grass sod, it is advisable to plow a furrow at the toe of the slope. Where a cutting passes into a fill all the vegetable matter should be removed from the surface before placing the fill. The site of the bank should be carefully examined and all deposits of soft, compressible matter removed. When a bank is to be made over a swamp or marsh, the site should be thoroughly drained, and if possible the fill should be started on hard bottom.

Perfect stability is the object aimed at, and all precautions necessary to this end should be taken. Embankments should be built in successive layers, banks two feet and under in layers from six inches to one foot, heavier banks in layers 2 and 3 feet thick. The horses and vehicles conveying the materials should be required to pass over the bank for the purpose of consolidating it, and care should be taken to have the layers dip towards the center. Embankments first built up in the center, and afterwards widened by dumping the earth over the sides, should not be allowed.

Embankments on Hillsides. When the axis of the road is laid out on the side slope of a hill, and the road is formed partly by excavating and partly by embanking, the usual and most simple method is to extend out the embankment gradually along the whole line of the excavation. This method is insecure; the excavated material if simply deposited on the natural slope is liable to slip, and no pains should be spared to give it a secure hold, particularly at the toe of the slope. The natural surface of the slope should be cut into steps as shown in Figs. 23 and 24. The dotted line A B

represents the natural surface of the ground, C E B the excavation, and A D C the embankment, resting on steps which have been cut between A and C. The best position for these steps is perpendicular to the axis of greatest pressure. If A D is inclined at the angle of repose of the material, the steps near A should be inclined in the

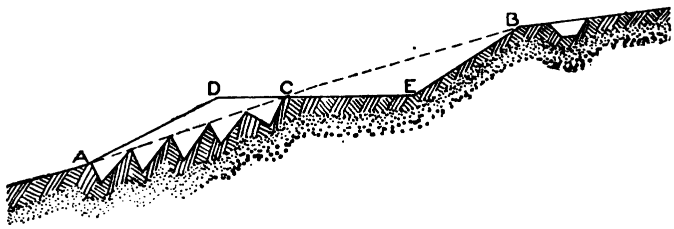

Fig. 23. Method of Construction on Hillsides.

opposite direction to A D, and at an angle of nearly 90 degrees thereto, while the steps near C may be level. If stone is abundant, the toe of the slope may be further secured by a dry wall of stone.

On hillsides of great inclination the above method of construction will not be sufficiently secure; retaining walls of stone must be substituted for the side slopes of both the excavations and embankments. These walls may be made of stone laid dry, when stone

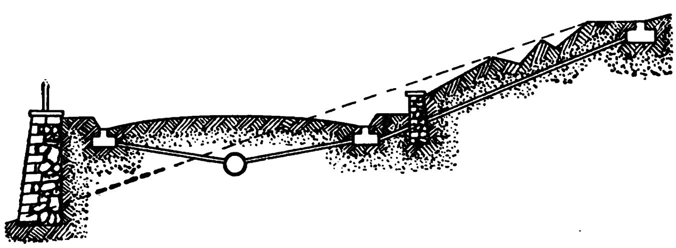

Fig. 24. Hillside Road with Retaining and Revetment Walls.

can be procured in blocks of sufficient size to render this kind of construction of sufficient stability to resist the pressure of the earth. When the stones laid dry do not offer this security, they must be laid in mortar. The wall which forms the slope of the excavation should be carried up as high as the natural surface of the ground. Unless the material is such that the slope may be safely formed into steps or benches as shown in Fig. 23, the wall that sustains the embankment should be built up to the surface of the roadway, and a parapet

wall or fence raised upon it, to protect pedestrians against accident. (See Fig. 24.)

For the formula for calculating the dimensions of retaining walls see instruction paper on Masonry Construction.

Roadways on Rock Slopes. On rock slopes when the inclination of the natural surface is not greater than one perpendicular to two base, the road may be constructed partly in excavation and partly in embankment in the usual manner, or by cutting the face of the slope into horizontal steps with vertical faces, and building up the embankment in the form of a solid stone wall in horizontal courses, laid either dry or in mortar. Care is required in proportioning the steps, as all attempts to lessen the quantity of excavation by increasing the number and diminishing the width of the steps require additional precautions against settlement in the built-up portion of the roadway.

When the rock slope has a greater inclination than 1 : 2 the whole of the roadway should be in excavation.

In some localities roads have been constructed along the face of nearly perpendicular cliffs on timber frameworks consisting of horizontal beams, firmly fixed at one end by being let into holes drilled in the rock, the other end being supported by an inclined strut resting against the rock in a shoulder cut to receive it. There are also examples of similar platforms suspended instead of being supported.

Earth Roads. The term "earth road" is applied to roads where the surface consists of the native soil; this class of road is the most common and cheapest in first cost. At certain seasons of the year earth roads when properly cared for are second to none, but during the spring and wet seasons they are very deficient in the important requisite of hardness, and are almost impassable.

For the construction of new earth roads, all the principles previously discussed relating to alignment, grades, drainage, width, etc., should be carefully followed. The crown or transverse contour should be greater than in stone roads. Twelve inches at the center in 25 feet will be sufficient.

Drainage is especially important, because the material of the road is more susceptible to the action of water, and more easily

destroyed by it than are the materials used in the construction of the better class of roads. When water is allowed to stand upon the road, the earth is softened, the wagon wheels penetrate it and the horses' feet mix and kneed it until it becomes impassable mud. The action of frost is also apt to be more disastrous upon the more permeable surface of the earth road, having the effect of swelling and heaving the roadway and throwing its surface out of shape. It may

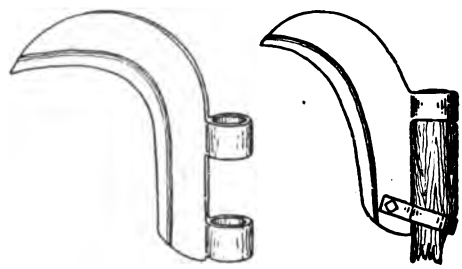

Fig. 25. Bush Hooks.

in fact be said that the whole problem of the improvement and maintenance of ordinary country roads is one of drainage.

In the preparation of the wheelway all stumps, brush, vegetable matter, rocks and boulders should be removed from the surface and the resulting holes filled in with clean earth. The roadbed having

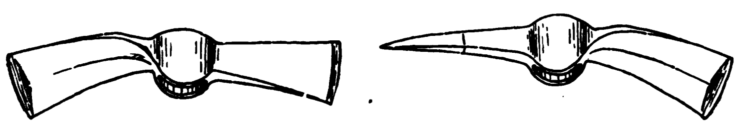

Fig. 26. Axe Mattock. Fig. 27. Bush Mattock.

been brought to the required grade and crown should be thoroughly rolled, all inequalities appearing during the rolling should be filled up and re-rolled.

Care of Earth Roads. If the surface of the roadway is properly formed and kept smooth, the water will be shed into the side ditches and do comparatively little harm; but if it remains upon the surface, it will be absorbed and convert the road into mud. All ruts and depressions should be filled up as soon as they appear. Repairs should be attended to particularly in the spring. At this season a judicious use of a road machine and rollers will make a

smooth road. In summer when the surface gets roughed up it can be improved by running a harrow over it; if the surface is a little muddy this treatment will hasten the drying.

During the fall the surface should be repaired, with special reference to putting it in shape to withstand the ravages of winter. Saucer-like depressions and ruts should be filled up with clean earth similar to that of the roadbed and tamped into place.

The side ditches should be examined in the fall to see that they are free from dead weeds and grass, and late in winter they should be examined again to see that they are not clogged. The mouths of culverts should be cleaned of rubbish and the outlet of tile drains opened. Attention to the side ditches will prevent overflow, and washing of the roadway, and will also prevent the formation of ponds at the roadside and the consequent saturation of the roadbed.

Holes and ruts should not be filled with stone, bricks, gravel or other material harder than the earth of the roadway as the hard material will not wear uniform with the rest of the road, but produce bumps and ridges, and usually result in making two holes, each larger than the original one. It is bad practice to cut a gutter from a hole to drain it to the side of the road. Filling is the proper course, whether the hole is dry or contains mud.

In the maintenance of clay roads neither sods nor turf should be used to fill holes or ruts; for, though at first deceptively tough, they soon decay and form the softest mud. Neither should the ruts be filled with field stones; they will not wear uniformly with the rest of the road, but will produce hard ridges.

Trees and close hedges should not be allowed within 200 feet of a clay road. It requires all the sun and wind possible to keep its surface in a dry and hard condition.

Sand Roads. The aim in the improvement of sand roads is to have the wheelway as narrow and well defined as possible, so as to have all the vehicles run in the same track. An abundant growth of vegetation should be encouraged on each side of the wheelway, for by this means the shearing of the sand is, in a great measure, avoided. Ditching beyond a slight depth to carry away the rain water is not desirable, for it tends to hasten the drying of the sands, which is to be avoided. Where possible the roads should be over-

hung with trees, the leaves and twigs of which catching on the wheelway will serve still further to diminish the effect of the wheels in moving the sands about. If clay can be obtained, a coating 6 inches thick will be found a most effective and economical improvement. A coating of 4 inches of loose straw will, after a few days' travel, grind into the sand and become as hard and as firm as a dry clay road.

The maintaining of smooth surfaces on all classes of earth roads will be greatly assisted and cheapened by the frequent use of a roller (either steam or horse) and any one of the various forms of road grading and scraping machines. In repairing an earth road the plough should not be used. It breaks up the surface which has been compacted by time and travel.

TOOLS FOR GRADING.

Picks are made of various styles, according to the class of material in which they are to be used. Fig. 28 shows the form

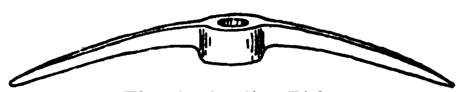

Fig. 28. Grading Pick.

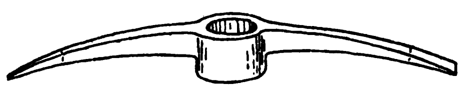

Fig. 29. Clay Pick.

usually employed in street work. Fig. 29 shows the form generally used for clay or gravel excavation.

The eye of the pick is generally formed of wrought iron, pointed with steel. The weight of picks ranges from 4 to 9 lb.

Fig. 30. Shovels.

Shovels are made in two forms, square and round pointed, usually of pressed steel.

Ploughs are extensively employed in grading, special forms being manufactured for the purpose. They are known as "grading ploughs," "road ploughs," "township ploughs," etc. They vary

in form according to the kind of work they are intended for, viz.: loosening earth, gravel, hardpan, and some of the softer rocks.

These ploughs are made of great strength, selected white oak, rock elm, wrought steel and iron being generally used in their construction. The cost of operating ploughs ranges from 2 to 5 cents per cubic yard, depending upon the compactness of the soil. The quantity of material loosened will vary from 2 to 5 cubic yards per hour.

Fig. 31 shows the form usually adopted for loosening earth. This plough does not turn the soil, but cuts a furrow about 10

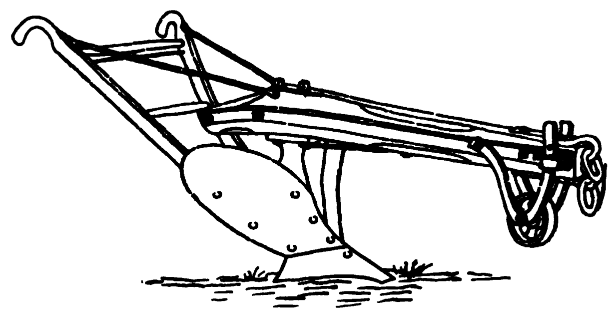

Fig. 31. Grading Plow.

inches wide and of a depth adjustable up to 11 inches.

In light soil the ploughs are operated by two or four horses; in heavy soils as many as eight are employed. Grading ploughs vary in weight from 100 to 325 lb.

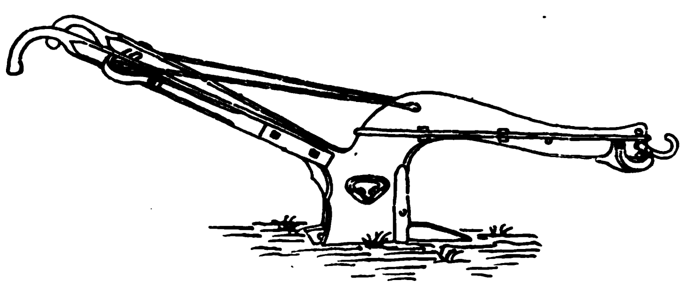

Fig. 32. Hardpan Plow.

Fig. 32 illustrates a plough specially designed for tearing up macadam, gravel, or similar material. The point is a straight bar of cast steel drawn down to a point, and can be easily repaired.

Scrapers are generally used to move the material loosened by ploughing; they are made of either iron or steel, and in a variety of form, and are known by various names, as "drag," "buck," "pole," and "wheeled". The drag scrapers are usually employed on short hauls, the wheeled on long hauls. Fig. 33 illustrates the usual form of drag scrapers.

Drag scrapers are made in three sizes. The smallest, for one horse, has a capacity of 3 cubic feet; the others, for two horses,

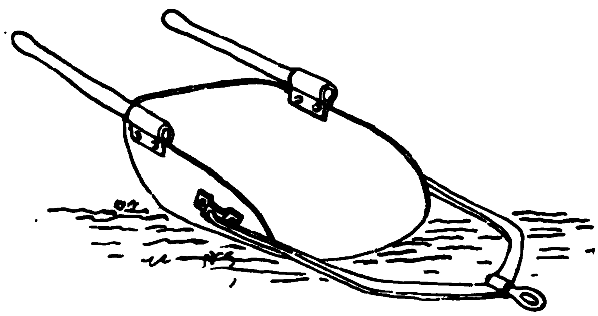

Fig. 33. Drag Scraper.

have a capacity of 5 to 7½ cubic feet. The smallest weighs about 90 lb., and the larger ones from 94 to 102 lb.

Buck scrapers are made in two sizes—two-horses, carrying 7½ cubic feet; four-horses, 12 cubic feet.

Pole scraper, Fig. 34, is designed for use in making and leveling earth roads and for cutting and cleaning ditches; it is also well

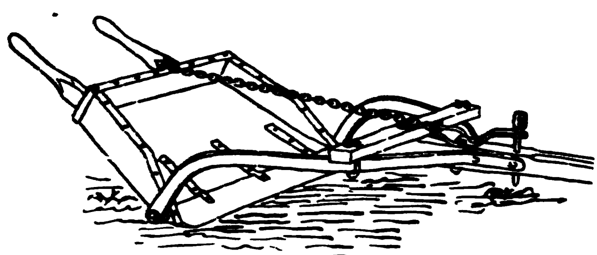

Fig. 34. Pole Scraper.

adapted for moving earth short distances at a minimum cost.

Wheeled scrapers consist of a metal box, usually steel, mounted on wheels, and furnished with levers for raising, lowering, and

dumping. They are operated in the same manner as drag scrapers, except that all the movements are made by means of the levers, and without stopping the team. By their use the excessive resistance to

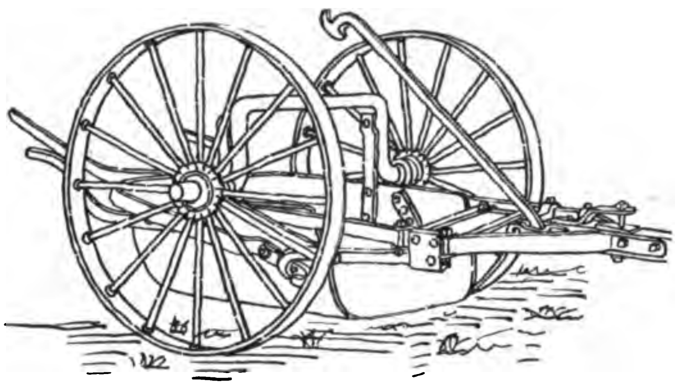

Fig. 35. Wheeled Scraper.

traction of the drag scraper is avoided. Various sizes are made, ranging in capacity from 10 to 17 cubic feet. In weight they range from 350 to 700 lb.

Wheelbarrows. The wheelbarrow shown in Fig. 36 is constructed of wood and is the most commonly employed for earthwork. Its capacity ranges from 2 to 2½ cubic feet. Weight about 50 lb.

The barrow, Fig. 37, has a pressed-steel tray, oak frame, and steel wheel, and will be found more durable in the maintenance

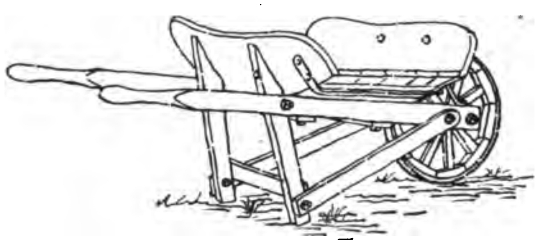

Fig. 36. Wooden Barrow.

department than the all wood barrow. Capacity from 3½ to 5 cubic feet, depending on size of tray.

The barrow, Fig. 38, is constructed with tubular iron frames and steel tray, and is adaptable to the heaviest work, such as

moving heavy broken stone, etc., or it may be employed with advantage in the cleaning department. Capacity from 3 to 4 cubic feet. Weight from 70 to 82 lb.

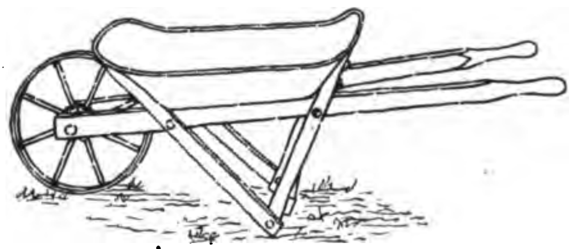

Fig. 37. Steel Tray Barrow.

The maximun distance to which earth can be moved economically in barrows is about 200 feet. The wheeling should be performed upon planks, whose steepest inclination should not exceed 1 in 12. The force required to move a barrow on a plank is about $\frac{1}{25}$ part of the weight; on hard dry earth, about $\frac{1}{14}$ part of the weight.

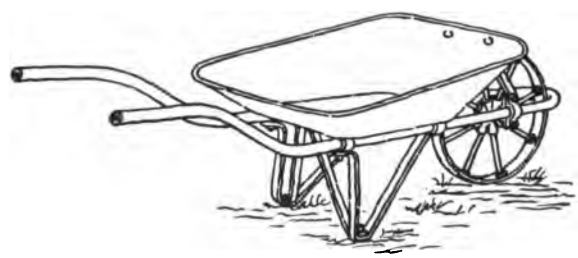

Fig. 38. Metal Barrow.

The time occupied in loading a barrow will vary with the character of the material and the proportion of wheelers to shovellers. Approximately, a shoveller takes about as long to fill a barrow with earth as a wheeler takes to wheel a full barrow a distance of about 100 or 120 feet on a horizontal plank and return with the empty barrow.

Carts. The cart usually employed for hauling earth, etc., is shown in Fig. 39. The average capacity is 22 cubic feet, and the average weight is 800 lb. These carts are usually furnished with broad tires, and the body is so balanced that the load is evenly divided about the axle.

The time required to load a cart varies with the material. One shoveller will require about as follows: Clay, seven minutes; loam, six minutes; sand, five minutes.

Fig. 39. Earth Wagon.

Dump Cars. These cars are made to dump in several different ways, viz., single or double side, single or double end, and rotary or universal dumpers.

Dump cars may be operated singly or in trains, as the magnitude of the work may demand. They may be moved by horses or

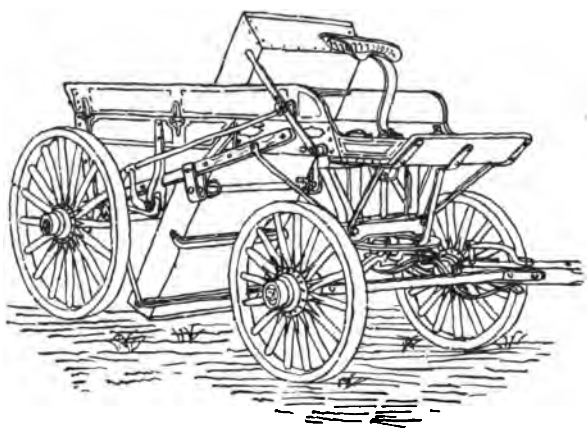

Fig. 40. Dump Cart.

small locomotives. They are made in various sizes, depending upon the gauge of the track on which they are run. A common gauge is

20 inches, but it varies from that up to the standard railroad gauge of 56½ inches.

Dump Wagons. (Fig. 40.) The use of these wagons for moving excavated earth, etc., and for transporting materials such as sand, gravel, etc., materially shortens the time required for unloading the ordinary form of contractor's wagon; having no reach or pole connecting the rear axle with the center bearing of the front axle, they may be cramped short and the load deposited just where required. They are operated by the driver, and the capacity ranges from 35 to 45 cubic feet.

Mechanical Graders are used extensively in the making and maintaining of earth roads. They excavate and move earth more expeditiously and economically than can be done by hand; they are called by various names, such as "road machines," "graders," "road hones," etc. Their general form is shown in Fig. 41.

Briefly described, they consist of a large blade made entirely of steel or of iron, or wood shod with steel, which is so arranged by mechanism attached to the frame from which it is suspended that it can be adjusted and fixed in any direction by the operator. In their action they combine the work of excavating and transporting the

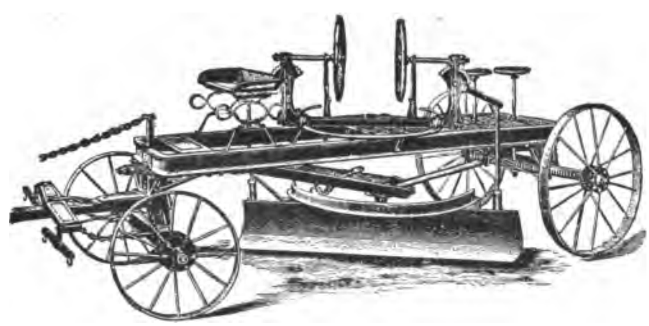

Fig. 41. Mechanical Grader.

earth. They have been chiefly employed in the forming and maintenance of earth roads, but may be also advantageously used in preparing the subgrade surface of roads for the reception of broken stone or other improved covering.

A large variety of such machines are on the market. The "New Era" grader excavates the material from side ditches, and

automatically loads the material into carts or wagons. Briefly described, the machine consists of a plough which loosens and raises the earth, depositing it upon a transverse carrying-belt, which conveys it from excavation to embankment. This carrier is built in four sections, bolted together, so it can be used to deliver earth at 14, 17, 19, or 22 feet from the plough. The carrier belt is of heavy 3-ply rubber 3 feet wide.

The plough and carrier are supported by a strong trussed framework resting on heavy steel axles and broad wheels. The large rear wheels are ratcheted upon the axle, and connected with strong gearing which propels the carrying-belt at right angles to the direction in which the machine is moving.

The wheels and trusses are low and broad, occupying a space 8 feet wide and 14 feet long, exclusive of the side carrier. This enables it to work on hillsides where any wheeled implements can be used. Notwithstanding its large size it is so flexible that it may be turned around on a 16-foot embankment. Pilot wheels and levers enable the operator to raise or lower the plough or carrier at pleasure.

As a motive power 12 horses—8 driven in front, 4 abreast, and 4 in the rear on a push cart—are usually employed.

When the teams are started, the operator lowers the plough and throws the belting into gear, and as the plough raises and turns the earth to the side the belt receives and delivers it at the distance for which the carrier is adjusted, forming either excavation or embankment.

When it becomes necessary to deliver the excavated earth beyond the capacity of the machine (22 feet or 7½ feet above the plough), the earth is loaded upon wagons, then conveyed to any distance. Arranging the carrier at 19 feet, wagons are driven under the carrier and loaded with 1¼ to 1½ yards of earth in from 20 to 30 seconds. When one wagon turns out with its load, another drives under the carrier, and the machine thus loads 600 to 800 wagons per day. It is claimed that with six teams and three men it is capable of excavating and placing in embankment from 1000 to 1500 cubic yards of earth in ten hours, or of loading from 600 to 800

wagons in the same time, and that the cost of this handling is from 1½ to 2½ cents per cubic yard.

Points to be Considered in Selecting a Road Machine. In the selection of a road machine the following points should be carefully considered:

(1) Thoroughness and simplicity of its mechanical construction.
(2) Material and workmanship used in its construction.
(3) Ease of operation.
(4) Lightness of draft.
(5) Adaptability for doing general road-work, ditching, etc.
(6) Safety to the operator.

Care of Road Machines. The road machine when not in use should be stored in a dry house and thoroughly cleaned, its blade brushed clean from all accumulations of mud, wiped thoroughly dry, and well covered with grease or crude oil. The axles, journals, and wearing parts should be kept well oiled when in use, and an extra blade should be kept on hand to avoid stopping the machine while the dulled one is being sharpened.

Surface Graders. The surface grader, Fig. 42, is used for removing earth previously loosened by a plough. It is operated by one horse. The load may be retained and carried a considerable

Fig. 42. Surface Grader.

distance, or it may be spread gradually as the operator desires. It is also employed to level off and trim the surface after scrapers.

The blade is of steel, ¼-inch thick, 15 inches wide, and 30 inches long. The beam and other parts are of oak and iron. Weight about 60 lb.

The road leveller, Fig. 43, is used for trimming and smoothing the surface of earth roads. It is largely employed in the Spring when the frost leaves the ground.

Fig. 43. Road Leveller.

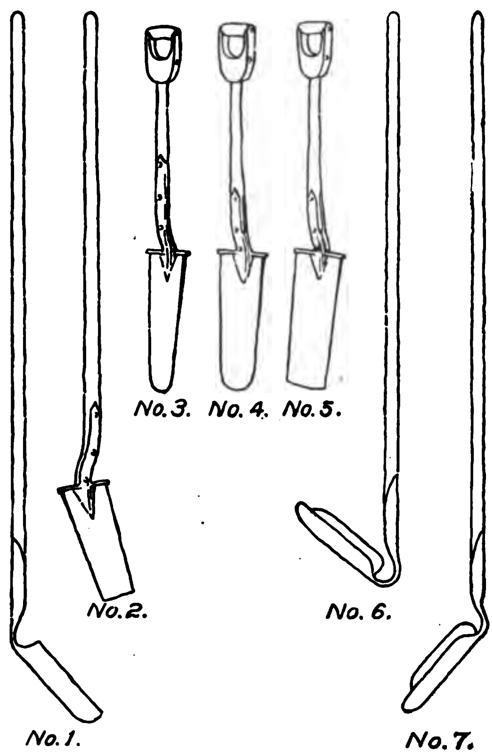

Fig. 44. Draining Tools.

The blade is of steel, $\frac{1}{4}$-inch thick by 4 inches by 72 inches, and is provided with a seat for the driver. It is operated by a team of horses. Weight about 150 lb.

Draining-tools. The tools employed for digging the ditches and shaping the bottom to fit the drain tiles are shown in Fig. 44. They are convenient to use, and expedite the work by avoiding unnecessary excavation.

The tools are used as follows: Nos. 3, 4 and 5 are used for digging the ditches; Nos. 6 and 7 for cleaning and rounding the

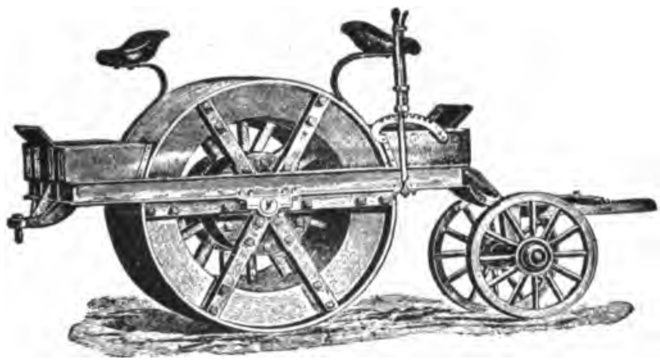

Fig. 45. Reversible Roller.

bottom of the ditch for round tile. No. 2 is used for shoveling out loose earth and levelling the bottom of the ditch; No. 1 is used for the same purpose when the ditch is intended for "sole" tile.

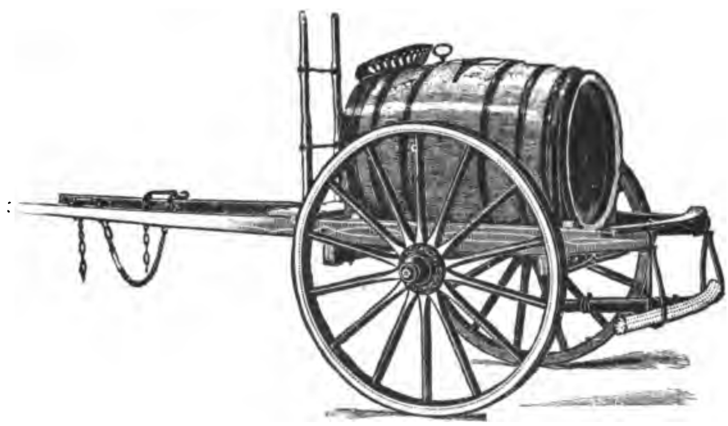

Fig. 46. Watering Cart.

Horse Rollers. There is a variety of horse rollers on the market. Fig. 45 shows the general form. Each consists essentially of a hollow cast-iron cylinder 4 to 5 feet long, 5 to 6 feet in

diameter, and weighing from 3 to 6 tons. Some forms are provided with boxes in which stone or iron may be placed to increase the weight, and some have closed ends and may be filled with water or sand.

Sprinkling-carts. Fig. 46 shows a convenient form of sprinkling cart for suburban streets and country roads. Capacity about 150 gallons.

ROAD COVERINGS.

Road coverings consist of some foreign material as gravel, broken stone, clay, etc., placed on the surface of the earth road. The object of this covering, whatever its nature, is (1) to protect the natural soil from the effect of weather and travel, and (2) to furnish a smooth surface on which the resistance to traction will be reduced to the least possible amount, and over which vehicles may pass with safety and expedition at all seasons of the year. Where an artificial covering is employed, the wheel loads coming upon its surface are distributed over a greater area of the roadbed than if the loads come directly upon the earth itself. The loads are not sustained by the covering as a rigid structure, but are transferred through it to the roadbed, which must support both the weight of the covering and the load coming upon it.

Gravel Roads. Gravel is an accumulation of small more or less rounded stones which usually vary from the size of a small pea to a walnut. It is often intermixed with other substances, such as sand, clay, loam, etc., from each of which it derives a distinctive name. In selecting gravel for road purposes the chief quality to be sought for is the property of binding.

Gravel in general is unserviceable for roadmaking. This is due mainly to the fact that the surface of the pebbles is smooth, so that they will not bind together in the manner of broken stone. There is also an absence of dust or other material to serve as a binder, and even if such binding material is furnished it is difficult to effectively hold the rounded and polished surface of the pebbles together.

In certain deposits of gravel, particularly where the pebbly matter is to a greater or less extent composed of limestone, a considerable amount of iron oxide has been gathered in the mass.

This effect is due to the tendency of water which contains iron to lay down that substance and to take lime in its place when the opportunity for so doing occurs. Such gravels are termed ferruginous. They are commonly found in a somewhat cemented state, and when broken up and placed upon roads they again cement, even more firmly than in the original state, often forming a roadway of very good quality.

When no gravel but that found in rivers or on the seashore can be obtained, one-half of the stone should be broken and mixed with the other half; to the stone so mixed a small quantity of clay or loam, about one-eighth of the bulk of the gravel, must be added: an excess is injurious. Sand is unsuitable. It prevents packing in proportion to the amount added.

Preparing the Gravel. Pit gravel usually contains too much earth, and should be screened before being used. Two sieves should be provided, one with meshes of one and one-half inches, so that all pebbles above that size may be rejected, the other with meshes of three quarters of an inch, and the material which passes through it should be thrown away. The expense of screening will be more than repaid by the superior condition of the road formed by the cleaned material, and by the diminution of labor in keeping it in order. The pebbles larger than one and a half inches may be broken to that size and mixed with clean material.

Laying the Gravel. On the roadbed properly prepared a layer of the prepared gravel four inches thick is uniformly spread over the whole width, then compacted with a roller weighing not less than two tons, and having a length of not less than thirty inches. The rolling must be continued until the pebbles cease to rise or creep in front of the roller. The surface must be moistened by sprinkling in advance of the roller, but too much water must not be used. Successive layers follow, each being treated in the above described manner until the requisite depth and form has been attained.

The gravel in the bottom layer must be no larger than that in the top layer; it must be uniformly mixed, large and small together, for if not, the vibration of the traffic and the action of frost will cause the larger pebbles to rise to the surface and the smaller ones to descend, and the road will never be smooth or firm.

The pebbles in a gravel road are simply imbedded in a paste and can be easily displaced. It is for this reason, among others, that such roads are subject to internal destruction.

The binding power of clay depends in a large measure upon the state of the weather. During rainy periods a gravel road becomes soft and muddy, while in very dry weather the clay will contract and crack, thus releasing the pebbles, and giving a loose surface. The most favorable conditions are obtained in moderately damp or dry weather, during which a gravel road offers several advantages for light traffic, the character of the drainage, etc., largely determining durability, cost, maintenance, etc.

Repair. Gravel roads constructed as above described will need but little repairs for some years, but daily attention is required to make these. A garden rake should be kept at hand to draw any loose gravel into the wheel tracks, and for filling any depressions that may occur.

In making repairs, it is best to apply a small quantity of gravel at a time, unless it is a spot which has actually cut through. Two inches of gravel at once is more profitable than a larger amount. Where a thick coating is applied at once it does not all pack, and if, after the surface is solid, a cut be made, loose gravel will be found; this holds water and makes the road heave and become spouty under the action of frost. It will cost no more to apply six inches of gravel at three different times than to do it at once.

At every one-eighth of a mile a few cubic yards of gravel should be stored to be used in filling depressions and ruts as fast as they appear, and there should be at least one laborer to every five miles of road.

Broken Stone Roads. Broken stone roads are formed by placing small angular fragments of stone on the surface of the earth roadbed and compacting into a solid mass by rolling. This class of road covering is generally called a Macadam or Telford road from the name of the two men who first introduced this type into England.

The name of Telford is associated with a rough stone foundation, which he did not always use, but which closely resembled that which had been previously used in France. Macadam disregarded

this foundation, contending that the subsoil, however bad, would carry any weight if made dry by drainage and kept dry by an impervious covering. The names of both have ever since been associated with the class of road which each favored, as well as with roads on which all their precepts have been disregarded.

Quality of Stones. The materials used for broken-stone pavements must of necessity vary very much according to the locality. Owing to the cost of haulage, local stone must generally be used, especially if the traffic be only moderate. If, however, the traffic is heavy, it will sometimes be found better and more economical to obtain a superior material, even at a higher cost, than the local stone; and in cases where the traffic is very great, the best material that can be obtained is the most economical.

The qualities required in a good road stone are hardness and and toughness and ability to resist the disintegrating action of the weather. These qualities are seldom found together in the same stone. Igneous and siliceous rocks, although frequently hard and tough, do not consolidate so well nor so quick as limestone, owing to the sandy detritus formed by the two first having no cohesion, whilst the limestone has a detritus which acts like mortar in binding the stones together.

A stone of good binding nature will frequently wear much better than one without, although it is not so hard. A limestone road well made and of good cross-section will be more impervious than any other, owing to this cause, and will not disintegrate so soon in dry weather, owing partly to this and partly to the well-known quality which all limestone has of absorbing moisture from the atmosphere. Mere hardness without toughness is not of much use, as a stone may be very hard but so brittle as to be crushed to powder under a heavy load, while a stone not so hard but having a greater degree of toughness will be uninjured.

By a stone of good binding quality is meant one that, when moistened by water and subjected to the pressure of loaded wheels or rollers, will bind or cement together. This quality is possessed to a greater or less extent by nearly all rocks when in a state of disintegration. The binding is caused by the action of water upon the chemical constituents of the stone contained in the detritus produced

by crushing the stone, and by the friction of the fragments on each other while being compacted; its strength varies with the different species of rock, but it exists in some measure with them all, being greatest with limestone and least with gneiss.

The essential condition of the stone to produce this binding effect is that it be sound. No decayed stone retains the property of binding, though in some few cases, where the material contains iron oxides, it may, by the cementing property of the oxide, undergo a certain binding.

A stone for a road surface should be as little absorptive of moisture as possible in order that it may not suffer injury from the action of frost. Many limestones are objectionable on this account.

The stone used should be uniform in quality, otherwise it will wear unevenly, and depressions will appear where the softer material has been used.

As the under parts of the road covering are not subject to the wear of traffic, and have only the weight of loads to sustain, it is not necessary that the stone of the lower layer be so hard or so tough as the stone for the surface, hence it is frequently possible by using an inferior stone for that portion of the work, to greatly reduce the cost of construction.

Size of Stones. The stone should be broken into fragments as nearly cubical as possible. The size of the cubes will depend upon the character of the rock. If it be granite or trap, they should not exceed 1½ inches in their greatest dimensions; if limestone, they should not exceed 2 inches.

The smaller the stones the less the percentage of voids. Small stones compact sooner, require less binding, and make a smoother surface than large ones, but the size of the stone for any particular section of a road must be determined to a certain extent by the amount of traffic which it will have to bear and the character of the rock used.

It is not necessary nor is it advisable that the stone should be all of the same size; they may be of all sizes under the maximum. In this condition the smaller stones fill the voids between the larger and less binding is required.

Thickness of the Broken Stone. The offices of the broken

stone are to endure friction and to shed water; its thickness must be regulated by the quality of the stone, the amount of traffic, and nature of the natural soil bed. Under heavy traffic it is advisable to make the thickness greater than for light traffic, in order to provide for wear and lessen the cost of renewals.

When the roadbed is firm, well drained, and not likely to be affected by ground water, it will always afford a firm foundation for the broken stone, the thickness of which may be made the minimum for good construction. This thickness is four inches. When this thickness is employed the stone must be of exceptionally fine quality and the road must be maintained by the "continuous" method. With heavy traffic the thickness should be increased over the minimum a certain amount, say 2 inches, to provide for wear. Where the foundation is unstable and there is a tendency on the part of the loads to break through the covering, the thickness of the stone must be made the maximum, which is 12 inches. In such a case it may be advisable to employ a Telford foundation. Where the covering exceeds six inches in thickness, the excess may be composed of gravel, sand or ledge stone, the choice depending entirely on the cost, for all are equally effective.

Foundation. The preparation of the natural soil over which the road is to be constructed, to enable it to sustain the superstructure and the weights brought upon it, requires the observance of certain precautions the neglect of which will sooner or later result in the deterioration or possible destruction of the road covering. These precautions vary with the character of the soil.

Soils of a siliceous and calcareous nature do not present any great difficulty, as their porous nature generally affords good natural drainage which secures a dry foundation. Their surface, however, requires to be compacted; this is effected by rolling.

The rolling should be carried out in dry weather, and any depressions caused by the passage of the roller should be filled with the same class of material as the surrounding soil. The rolling must be repeated until a uniform and solid bed is obtained.

The argillaceous and allied soils, owing to their retentive nature, are very unstable under the action of water and frost, and in their natural condition afford a poor foundation. The prepara-

tion of such soil is effected by drainage and by the application of a layer of suitable material to entirely separate the surface from the road material. This material may be sand, furnace ashes, or other material of a similar nature, spread in a layer from 3 to 6 inches thick over the surface of the natural soil.

When the road is formed in rock cuttings it is advisable to spread a layer of sand or other material of light nature, so as to fill up the irregularities of the surface as well as to form a cushion for the road material to rest on.

Spreading the Stone. The stone should be hauled upon the roadbed in broad-tire two-wheeled carts and dumped in heaps and be spread evenly with a rake in a layer which should be of a depth of 4½ inches.

Watering. Wetting the stone expedites the consolidation, decreases crushing under the roller, and assists the filling of the voids with the binder. It should be applied by a sprinkler and should not be thrown on in quantity or from the plain nozzle of a hose.

Excessive watering, especially in the earlier stages, tends to soften the foundation, and care should be exercised in its application.

Binding. As the voids in loosely spread broken stone range from 35 to 50 per cent of the volume, and as no amount of rolling will reduce the voids more than one-half, it is necessary, in order to form an impervious and compact mass, to add some fine material which is called the binder. It may consist of the fragments and detritus obtained in crushing the stone. When this is insufficient, as will be the case with the harder rocks, the deficiency may be made up of clean sand or gravel. The proportion of binder should slightly exceed the voids in the aggregate; it must not be mixed with the stones, but should be spread uniformly in small quantities over the surface and rolled into the interstices with the aid of water and brooms.

As the quality of the binding used is of vital importance, the employment of inferior material, such as road scrapings or material of a clayey nature, should be avoided, even if the initial cost of the work should be greater when a good binding material is used.

Stone consolidated with improper binding material may present a good appearance immediately after being rolled and be otherwise an apparently good piece of work, still in damp weather a considerable amount of "licking up" by the wheels of the vehicles will take place, which reduces the strength of the coating and causes the surface to wear unequally.

By the application of an immoderate quantity of binding of any description the stone coating will become unsound or rotten in condition, and if the binding be of an argillaceous nature, it will expand during frost, owing to its absorbent properties, and cause the displacement of the stones. The surface will become sticky, which seriously affects the tractive power of horses, while the road itself will suffer by the irregular deterioration of the surface.

The use of such material as mentioned for binding enables rolling to be accomplished in much less time than when proper binding is used, and the cost of consolidating the stone may be reduced by 25 per cent; but, on the other hand, the stone coating which will probably contain under these circumstances from 30 to 40 per cent of soft and soluble matter, and possibly present a smooth surface immediately after being rolled, will quickly become "cupped" by the wheel traffic, a bumpy surface being the result. This is caused by the irregular wear, while the lasting qualities or "life" of the coating will be shortened, giving unsatisfactory results to those traveling over the road, and the work of renewing the surface of the road in this manner may prove a failure on economical grounds. There can be no doubt, and it is now being more generally recognized, that sand as a material for binding in connection with rolling operations, when applied in a limited but sufficient quantity, promotes the durability of the stone coating, while the general results are equally satisfactory; a firm, compact, and smooth surface is obtained, and the subsequent maintenance of the road is minimized.

A great amount of rolling is necessary when sand is employed as a binding material, but economy is promoted, and the results are more satisfactory when sand is used than by the use of the material which gives to the stone an appearance only of having been properly consolidated. If clean sand be used in combination with the screenings from the crusher a very satisfactory surface will be obtained.

If the use of motor vehicles equipped with pueumatic tires becomes general, it is possible that some other description of binding material will be necessary. The pumping action of suction created by pneumatic tires, especially when propelled at a high speed, causes a considerable movement of the fine particles of the binding material, which on being displaced will convert the covering into a mass of stones. This objection can probably be overcome by watering.

Compacting the Broken Stone. Three methods of compacting the broken stone are practiced: (1) by the traffic passing over the road; (2) by rollers drawn by horses; (3) by rollers propelled by steam.

The first method is both defective and objectionable. (1) It is destructive to the horses and vehicles using the road. (2) It is wasteful of material; about one-third of the stone is worn away in the operation. (3) Dung and dust are ground up with the stone, and the road is more readily affected by wet and frost.

Steam-rollers were first successfully introduced in France in 1860, since which time they have been almost universally adopted on account of the superiority and economy of the work done. Their use shortens the time required for construction or repair, and effects an indirect saving by the reduced wear and tear of horses and vehicles. They are made in different weights ranging from 3 to 30 tons. For the compacting of broken stone roads the weights in favor are from ten to fifteen tons; the heavier weights are considered unwieldy and their use is liable to cause damage to the underground structures that may be in the roadway.

The advantage of steam rolling may be summed up as follows:

(1) They shorten the time of construction.

(2) A saving of road material, (a) because there are no loose stones to be kicked about and worn; (b) because there is no abrasion of the stone, only one surfacc of the stone being exposed to wear; (c) because a thinner coating of stone can be employed; (d) because no ruts can be formed in which water can lie to rot the stone.

(3) Steam-rolled roads are easier to travel on account of their even surface and superior hardness and they have a better appearance.

(4) The roads can be repaired at any season of the year.

(5) Saving both in materials and manual labor.

22nd. Examination Paper. _ Excellent —

EXAMINATION PAPER

HIGHWAY CONSTRUCTION

PART I

Read Carefully: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. ***Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure that you understand the subject.***

1. Upon what does the ease with which a vehicle can be moved on a road depend?
2. What kind of a road surface offers the greatest resistance to traction?
3. How may the power required to draw a vehicle over a projecting stone be calculated?
4. What effect has gravity on the load a horse can pull?
5. Under what condition is the tractive power of a horse decreased?
6. What are the best methods for improving sand roads?
7. State briefly how earth is loosened and transported and the conditions under which each method is most advantageous?
8. What are the essential requisites for securing a good gravel road?
9. How should gravel roads be repaired?
10. State the considerations that control the maximum grade.
11. How should different grades be joined?
12. What considerations control the width of a road?
13. What is the essential quality of a stone used for road covering?
14. What should be the shape and size of broken stone?
15. For a light traffic road what thickness should the layer of broken stone have?
16. How should the foundation for the broken stone be prepared?

17. What effect will the application of a large quantity of water have on the road?

18. What office does the binding fill? What quality should it possess and how much should be used?

19. What is the tractive power of a horse in pounds when traveling at the rate of three miles per hour?

20. Why are steep grades objectionable?

21. What are the two essential requisites of a good road?

22. What is the use of contour lines?

23. How is the cost of constructing a road affected by the location of its center line?

24. How should the location of mountain roads be conducted and why?

25. What condition of alignment of a road increases the cost of constructing and traveling on it?

26. What precautions should be observed in the construction of pipe culverts?

27. How should the slopes of embankments and cuttings be formed?

28. What change takes place in excavated materials?

29. How should embankments be formed on hillsides?

30. How should earth roads be cared for?

31. What should be the transverse shape of a road and why?

32. How is the ground water removed from the site of a road?

33. State the information required in determining the area of a culvert.

34. How may the discharging capacity of a culvert be increased?

35. What precautions are required in the construction of pipe culverts?

After completing the work, add and sign the following statement:

I hereby certify that the above work is entirely my own.

(Signed)

Fig 1

Fig 1